

# Resilience to food insecurity: Measuring access to food in the urban environment

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by

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*For Emma*

Nā tō rourou, nā taku rourou

ka ora ai te iwi

*With your food basket, and my food basket*

*the people will thrive*

Māori whakataukī

# ABSTRACT

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Food security in urban environments is becoming an increasingly important issue worldwide; urban expansion and urban infilling means that city populations are rising while the amount of available land for growing food is reducing. Accessibility of food, in regards to potential food growing space and food retail locations at the household level, is a key indicator for determining how resilient households are to food insecurity.

This thesis investigates accessibility of food in urban environments, and a methodology has been developed that employs a non location-specific data structure that assigns resilience categories to individual households. User-defined input variables for the amount of food-growing space required per person, and the maximum travel distance allowed, mean that different scenarios can be created.

Two case studies of Christchurch and Stockholm are used to demonstrate how different datasets can be incorporated to give insight into the levels of resilience to food insecurity. Examples of potential sources of error caused by the variations in input dataset quality have been uncovered in the case studies, and possible strategies for dealing with these sources of error are discussed.

Results of this study showed that greater maximum travel distances play a key role in accessibility of food in the urban environment, and that both cities are reliant on food retailers to supply food to the urban population, even when potential food growing space is taken into account.

City planners or decision-makers can use the methodology developed in this thesis to make decisions about where potential growing space needs to be protected or allocated. They can also use it to model the potential effects of different scenarios, such as the addition of new subdivisions or changes in land use for public land.



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# 1 INTRODUCTION

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Urban expansion and urban drift are causing increases in city populations across the globe; forecasts predict that 70% of the planet's human population will be living in urban areas by 2050 (WHO, 2013). These urban population increases have led to a growing dependence on imported food. This phenomenon, coupled with rising food prices, has seen a greater focus on the concept of food insecurity, which is taking centre stage on a global level, rather than being predominantly considered in the context of developing nations.

Over the past two decades, many cities, regions, and countries have produced food strategies in an attempt to address some of the issues relating to food insecurity, some examples are London (London Development Agency, 2006) Manchester (Food Futures, 2007), Islington (NHS Islington and Islington Council, 2010), Toronto (Toronto Food Policy Council, 2013), Canada (Canadian Federation for Agriculture (CFA), 2011) and South Australia (Government of South Australia, 2010). Policy guidelines have been put in place to increase awareness of healthy food, promote urban agriculture and attempt to decrease the carbon footprint of food production and transport. New Zealand (Green Party of Aotearoa New Zealand, 2013), and Sweden (Kuylenstierna & Forsse, 2013) are two examples of countries continuing this trend by proposing or preparing food strategies.

Although these food strategies vary in their scope, some of the common themes include: promoting the freshness and nutritional value of locally-grown food; educating about and promoting healthy eating; ensuring the availability of safe and nutritious food at affordable prices; encouraging the provision of infrastructure for processing and distributing of food locally; ensuring a balance between food production and green energy production; and making food production more sustainable. Many of these themes involve the use and promotion of urban and peri-urban agriculture.

Food security, as defined at the World Food Summit of 1996, exists, “when all people at all times have access to sufficient safe, nutritious food to maintain a healthy and active life” (WHO, 2014, para.1)

The focus on urban food security has prompted a number of recent studies investigating whether sufficient food can be grown within cities to supply their populations’ daily nutritional requirements.

Research has been conducted on the amount of land potentially available for urban agriculture, the amount of land required to produce sufficient food for the population, how much land is being used, and the types of land that are available.

Imported food comes with extra transportation costs over food grown locally, and with the inevitable rise in fuel costs caused by peak oil, the cost of transport, and therefore the overall food price, will rise accordingly. Figure 1 shows the historic relationship between food costs and fuel price (Oil Price, 2014).

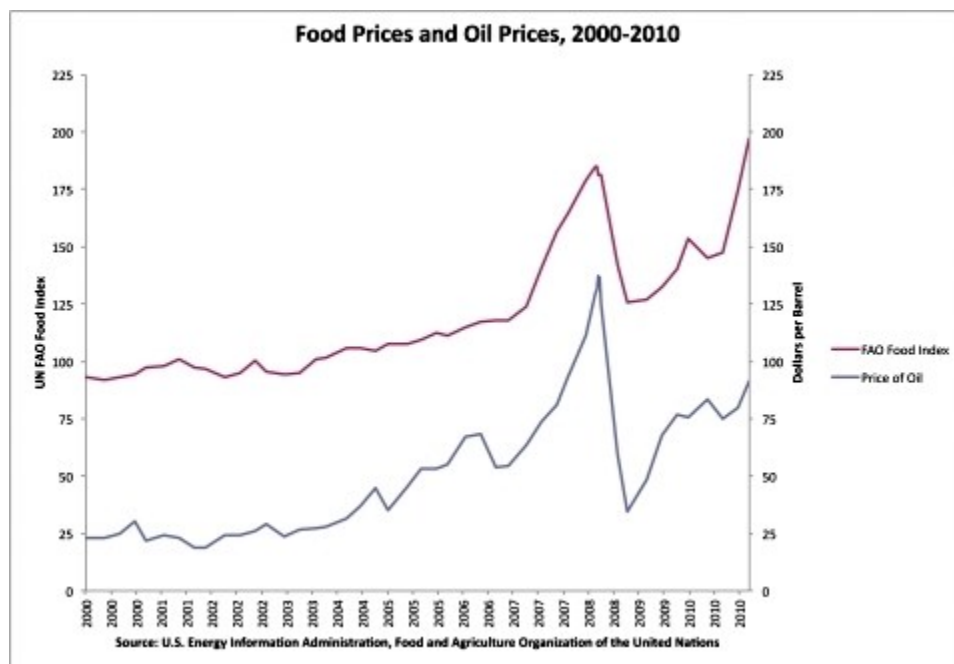


Figure 1. The relationship between fuel price and food costs (Oil Price, 2014)

To understand the effects of rising fuel costs resulting from peak oil, research into the accessibility of food retailers, schools, medical institutions, employment opportunities and other key locations has been

completed (Rendall, Page, Reitsma, Van Houten, & Krumdieck, 2011). However, research into accessibility has not yet extended to investigating how accessible food growing space is at the household level.

Accessibility of growing space at the household level is a key area that needs to be examined; since as well as establishing whether a city has enough land available to be self sufficient, it is also important to know if the food produced is easily accessible for the urban population. Increasing the amount of food provided through urban agricultural practices and growing more food reasonably close to where it is consumed, means that nutritious food can be made available with reasonable transport costs, resulting in more food-secure cities. Information about the accessibility of growing space at the household level feeds into decision-making processes, enabling better targeting of new locations for urban agricultural activity and identifying potential food desert areas within the city limits.

Using the cities of Christchurch, New Zealand, and Stockholm, Sweden, as case studies, this thesis develops a methodology for investigating the level of accessibility of food-growing space in cities. This methodology incorporates the use of GIS in order to gain insight into the location and quantity of land available for urban agricultural production, and also create a picture of how accessible this land is to each urban household. Household-level results give an indication of the level of self sufficiency, in terms of whether the household can supply its members with enough space to grow food on private land, or whether other food growing space is available locally. The results also give an indication of how accessible food retailers are to each household. The main contribution that this study makes to the field of research into resilience to food insecurity is the development of a decision support tool that can assist planners and decision-makers to decide where land could be protected for food production, or to look at the impact of urban expansion or infill housing on food-growing space.

The structure of the thesis is as follows: Chapter 2 reviews the relevant literature on urban agriculture and its role in food security, land availability, land requirements, land use and urban food accessibility.

Chapter 3 presents the methodological approach developed in the course of this study, in particular the data requirements, pre-processing and geo-processing. The application of the methodology to the case study cities of Christchurch, New Zealand, and Stockholm, Sweden is also described.

Chapter 4 presents the results for the two case studies with respect to access to potential growing space, and to food retailers.

These results are discussed in Chapter 5 as they relate to potential growing space, potential growing space required, capacitated location allocation, population, property ownership and accessibility, and suggests potential future research directions opened up by this research.

Chapter 6 concludes the thesis by outlining the contribution of this study to the field of research into resilience to food insecurity,

## 2 LITERATURE REVIEW

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### 2.1 URBAN AGRICULTURE AND ITS ROLE IN FOOD SECURITY

The FAO (1999, Sec IV) characterises urban agriculture as consisting of “...small areas (e.g. vacant plots, gardens, verges, balconies, containers) within the city for growing crops and raising small livestock or milk cows for own-consumption or sale in neighbourhood markets.” Peri-urban agriculture is defined as “...farm units close to town which operate intensive semi- or fully commercial farms to grow vegetables and other horticulture, raise chickens and other livestock, and produce milk and eggs.”

The concept of urban agriculture is certainly not new, there is evidence of urban agriculture dating back as far as the pre-Columbian Mayan cities in Meso-America (Barthel & Isendahl, 2013). Many cities around the world produce large quantities of food from within their boundaries today; Colasanti & Hamm (2010) cite several works that describe cities with high levels of self-sufficiency with regard to food, these include: Shanghai and Beijing (China); Brazzaville (Congo); Dar Es Salaam (Tanzania); and Accra (Ghana).

Urban agriculture, in the form of community and household gardens, is now commonplace in many cities, and there has been a resurgence in recent years in garden numbers in the UK, Canada, US, Australia and New Zealand (Green, 2012), (Soil and Health Association of New Zealand, 2013). Community gardening has a long history in industrialised cities around the world, particularly during times of hardship. During WWII, Chicago was home to more than 1,500 community gardens and over 250,000 household gardens (Taylor & Lovell, 2012). In the UK, even though imported food was still needed to assist with feeding the nation during the war (particularly wheat, fats and sugar), allotments and household gardens produced large quantities of vegetables that increased nutrition in a largely bulk wheat-, potato-, and powdered egg-centric diet (Defra. Food Chain Analysis Group, 2006). Community gardening has seen a recent revival –

between 2005 and 2010, a four-fold increase in the number of community gardens was found in the UK, and the proportion of the population involved with community gardening rose from 4% to 14% between 2003 and 2007 (Hart, 2014).

On a larger scale, peri-urban areas have also been included in the food strategy literature, particularly in relation to greenbelts and greenbelt farming. In Ontario, Canada, a large permanent greenbelt was created in 2005 around the urban areas of several cities. This was done for several reasons: to stop urban sprawl, to offer space for leisure activities, and also to provide agricultural land and clean water for the production of local food (The Ontario Greenbelt Alliance, 2013). In the UK, greenbelts have been in existence for over a hundred years. The first example was 500 hectares purchased from local landowners to be made into a greenbelt with an agricultural purpose: to supply produce to the newly-founded Letchworth Garden city in 1909 (Amati & Yokohari, 2006). Greenbelts or ‘foodbelts’ are an important resource for cities that have little land available for agriculture within the bounds of the built-up urban area. Increasing the amount of food produced through urban agriculture practices offers greater resilience to food insecurity by removing the need to transport food over great distances.

## **2.2 LAND AVAILABILITY**

When attempting to calculate how much food can be produced within a city’s urban area, one of the fundamental questions is “how much land is available?” The amount of available land varies depending on the definition of “available” that is used. Factors that need to be considered when defining what constitutes available land include: ownership, suitability for food production, and proximity to residential areas.

### **2.2.1 Land ownership**

Land ownership is an important consideration, since it is not possible to say that all privately-owned vacant land is available for household food production; it may instead be used for commercial food

production or for other purposes, such as storage of vehicles or machinery, golf courses, or animal holding areas.

It is more straightforward to identify government-owned or administered land that is available for food production. Although some areas used for recreation or conservation purposes may be sensitive, most public land should be available for food production if the need arises, as was the case of the victory gardens during WWII where recreation fields were converted into food growing spaces. However, government-owned land that may be considered vacant may still be used, for purposes such as; flood water overflows; airport landing paths; and coastal erosion reserves. These uses make the land unsuitable for food production for obvious reasons.

Different combinations of publicly- and privately-owned land have been used in accessibility studies investigating vacant land suitable for food production. In McLintock, Cooper, & Khandeshi's (2013) study assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California, both publicly- and privately-owned land was included, and strict rules around land cover types and minimum area measurements were applied. Only land parcels that included the prescribed space were included, recreation areas and most car parks were excluded. Some abandoned car parks were included, however, as these could be used for raised beds or greenhouse agriculture. Including privately-owned vacant or seemingly derelict land for urban agriculture is not without its problems.

Research undertaken by Lynch, Binns, & Olofin, (2001) revealed that a problem for many urban farmers in Kano, Nigeria, was insecure land tenure, and that many of the cultivated sites were under constant threat of development. Colasanti & Hamm (2010) included only publicly-owned land in their study, again removing the recreation spaces so as to give a conservative estimate of un-utilised land. This meant that the resulting production potential was underestimated.

Grewal and Grewal (2012), opted for a more inclusive estimate, breaking down available space into vacant lots (all), occupied lots (residential) and rooftops (commercial and industrial). Three different

scenarios were used to calculate the amount of available space in the city of Cleveland, Ohio, USA:

scenario 1 included the use of 80% of every vacant lot in the city; scenario 2 included an extra 9% of all occupied residential lots; and scenario 3 added an extra 62% of industrial and commercial rooftop areas.

## **2.2.2 Land suitability for food production**

In addition to actual measured space, other variables that relate to land quality – such as soil quality, soil contamination, and site characteristics – need to be considered when calculating how much land is available for food production.

### **2.2.2.1 Soil quality**

Soil types can be divided into categories that describe a level of fitness for purpose for agricultural use.

Webb, Smith, & Trangmar (2011) divide the soils of Christchurch, NZ, into six “soil versatility classes” which denote the relative versatility of the soil, in terms of the range of crops that can be grown, along with the soil management techniques that may be required to conserve the soils. When taking soil quality into account, high quality native soils are the best option, however, lesser quality soils can be improved by using organic composts and fertilisers to build soil quality (Cooperband, 2002). Alternatively, higher quality soils can be imported; this is often the practice when using raised beds or greenhouses, particularly in urban agriculture.

### **2.2.2.2 Soil contamination**

Contaminated soils for food production create an extra dimension of risk to health, and this risk is especially prevalent in the urban environment where soils used are located near roads or contaminated sites. The conversion of road reserves to food production spaces may be less than ideal, as the presence of heavy metals such as lead, zinc and other chemical pollutants produced by motor vehicles at a close proximity to food growing sites is considered to be a source of risk to human health. This risk can be lowered or even eliminated by situating food growing areas away from heavily-travelled roads and using cleaner imported soils in raised beds (Crozier, Bradley, & Polizzotto, ND).



Historic land use also needs to be taken into account when looking at converting vacant, unused or abandoned land. Sites such as post-industrial landscapes (McClintock, 2012), areas of historic farming activity, and old timber treatment plants, can all contain hazardous contaminants (MFE, 2013).

#### **2.2.2.3 Site characteristics**

The production of food at some sites may be impractical; the physical characteristics of a site, such as slope and aspect, may determine whether it is deemed to be suitable. Slope and aspect are important variables in agricultural practice. In McIntock, Cooper, & Khandeshi's study (2013), the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California is examined. In this study a slope threshold of 30% was used and they noted that steeper slopes can be, and are cultivated, but often terracing or other stabilisation techniques will be needed to make agricultural production practicable. When discussing aspect they promoted sites with a W, SW, S, SE or E aspect as being "optimal".

#### **2.2.3 Identifying growing space available at the residential parcel level**

A further challenge for the identification of true potential space for food production arises from the fact that while it may be possible to ascertain whether a private dwelling has a garden or not, it is difficult to know how much of that garden is actually available for growing food. Extra utility buildings, such as garages, sheds and sunrooms, along with patios, driveways and ornamental flower gardens, can decrease the amount of space a private home owner has to grow food in. This, coupled with the recent trend towards easy-care gardens for modern living may leave some private residences with little or no space available for growing food.

While a simple calculation of vacant land may suffice at the level of the city, when looking at resilience to food insecurity at a household level, it is important to know how much space is available at the residential parcel level. For example, some households on larger sections will have more than adequate space to

grow enough food for the household members, but those who reside in an apartment building may be lucky to have a balcony where they can cultivate a small herb garden.

The use of aerial or satellite imagery has made it possible to use desktop image analysis techniques to identify and classify different land cover types. McLintock, Cooper, & Khandeshi (2013) used various imagery datasets to visually interpret land cover; this enabled them to exclude parcels of land with land cover types that didn't fit the criteria they had selected. While this would have been extremely time consuming, it usefully removed a degree of error in which parcels with large areas of buildings or dense vegetation were removed from the total area of vacant space.

In research on food growing potential for Philadelphia, Kremer & DeLiberty (2011), used a combination of one-metre, high-resolution satellite imagery classified by object-oriented supervised classification, and NDVI classification. The combined classified satellite data was then combined with other vector GIS data to create an overall land cover classification map of residential property in the City of Philadelphia. The research included a comparison of the object-oriented (maximum likelihood) and NDVI classifications. The results gave a 6% discrepancy which was put down to the NDVI's difficulty with identifying bare soil, and the supervised classification training set containing pixels that were not green in the *grass* class. Once the classification was completed, areas outside of the residential parcels, and building footprints were removed. The results of this analysis allowed for the creation of a land cover dataset for the city with classes for trees, grass, bare soil and buildings (or other impermeable surfaces); this dataset could be used to identify potential food-growing space.

Renaud, Claire, & Jagannath (2007) used object-oriented classification to automatically map private gardens in urban environments using very high resolution multispectral *Ikonos* imagery; this resulted in a land cover map which identified over 90% of land cover correctly. Although classified imagery can offer a relatively quick result when compared to manual digitising, when it is compared to high resolution aerial photography, high resolution multi-spectral imagery is expensive and therefore may not always be available. When digitising manually using high resolution aerial photography, the user can not only

identify small features accurately, but can also add an extra degree of accuracy when looking at features that are spectrally similar. Using object-oriented classification on lower resolution multispectral imagery does not offer the same accuracies, and smaller features such as small streams can be lost (Cunningham, 2006). This accuracy is an important dimension of land cover mapping, particularly at the scale of private gardens where target areas can be small.

## **2.3 LAND REQUIRED**

The question of how much land is required to feed the population of the city is inherently difficult to answer; there will be as many answers as there are cities around the world. As well as the variables discussed earlier, such as soil type and physical geography, variables such as agricultural techniques used, and dietary preference also play a large part in determining how much space is required. This section discusses research completed in several cities in order to gain insight into some of the parameters that need to be taken into account when calculating the quantity of land that is required.

### **2.3.1 Agricultural techniques**

There are many different agricultural production techniques and these will offer varying yields. Colasanti & Hamm (2010) used three different production scenarios to give varying yield measurements: low-productivity bio-intensive, high-productivity bio-intensive, and commercial yield. Similarly, McLintock, Cooper, & Khandeshi (2013) followed with a model using average state-wide conventional agriculture yield data from California, low-productivity bio-intensive yields, and medium-productivity bio-intensive yields. Both studies found that using bio-intensive methods, even at a low productivity level, resulted in higher yields.

The bio-intensive agriculture method was popularised by John Jeavons and Ecology Action with the book *How to Grow More Vegetables: And Fruits, Nuts, Berries, Grains, and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine*, which was first published in 1974. The method was based on the Biodynamic/French intensive method developed by Alan Chadwick, and incorporates

traditional agricultural techniques, thousands of years old, used by the Chinese, the Mayans, and other cultures across the globe. The technique allows maximum yields in a minimal amount of space, and has a focus on soil building and composting to keep soils healthy (Jeavons, 2002, p. xiii).

In his book, Jeavons estimates that the current “approximate area required to grow one person’s diet using conventional mechanized chemical or organic techniques” ranges between 7,000 sq. ft. (650m<sup>2</sup>) for a vegan diet to up to 63,000 sq. ft. (5,853m<sup>2</sup>) for a high meat diet. He compares this to the “area required to grow one person’s diet with the grow biointensive method” (intermediate yields) being 4,000 sq. ft (372m<sup>2</sup>) (Jeavons, 2002, p. xiii).

Using these techniques coupled with expert knowledge in very intensive situations can result in much higher yields. In 1991, an eight person team entered Biosphere 2, an earth systems science research facility in Oracle, Arizona. The inhabitants were to live independently for two years within the closed agriculture system. Using bio-intensive agricultural techniques, the crew farmed a plot of just 2,000m<sup>2</sup> and managed to produce 85% of their food for the two years; however, research showed that the glass on the biosphere reduced light and UV rays which impacted on yields. After installing extra lighting, an eight-month, seven-member crew mission was completed in 1994 where 100% of their food was produced (Poynter & Bearden, 2013).

When it comes to allotment gardening, in the UK the accepted size of a plot is 250m<sup>2</sup>, this is considered the minimum area required to sustain a family year round, (National Society of Allotment and Leisure Gardeners Ltd, 2013, Scottish Government, 2013). Throughout Europe, allotment sizes range between 60 m<sup>2</sup> and 400m<sup>2</sup> (Office International du Coin de Terre et des Jardins Familiaux, 2013). Smaller plots are available for smaller families or beginner gardeners who prefer a smaller area to work with. For new allotment gardeners, some allotments offer a small plot with an opportunity to upsize once the gardener has gained the extra competencies required (Armstrong, Raper, & Whewell, 2010).

The Dervaes family, of the 'Urban Homestead' fame, grow enough food on their 1/10<sup>th</sup> acre plot in Pasadena, California, to supply 90% of their food consumption. This includes growing 99% of produce, raising livestock, and keeping bees for honey (Dervaes, 2013).

In his article "Can Britain feed itself?" Simon Fairlie estimates that one hectare of land is enough to feed eight people following an organic vegan diet, and, if a livestock permaculture approach is followed, 1.8 hectares could supply enough food for eight people (Fairlie, 2007). These figures were based on using large foodshed areas on a national scale, including woodland, pasture and arable farming and the use of tractor or horse power. This means that the figures may not be entirely applicable to small private garden settings.

Meyers (1998), cites the FAO document, *Soil Loss Accelerating Worldwide* (1993), which concluded that,

*The minimum amount of agricultural land necessary for sustainable food security, with a diversified diet similar to those of North America and Western Europe (hence including meat), is 0.5 of a hectare per person. This does not allow for any land degradation such as soil erosion, and it assumes adequate water supplies. Very few populous countries have more than an average of 0.25 of a hectare. It is realistic to suppose that the absolute minimum of arable land to support one person is a mere 0.07 of a hectare—and this assumes a largely vegetarian diet, no land degradation or water shortages, virtually no post-harvest waste, and farmers who know precisely when and how to plant, fertilize, irrigate, etc.*

This shows that dietary preference, in terms of whether meat or other animal-derived produce is included, can lead to large disparities in the amount of land required. Further to this, Peters, Wilkins, & Fick (2007), discovered that a vegan diet required only one-fifth of the space required to support a heavily meat-based diet; the annual land requirements are 0.18 ha and 0.86 ha respectively. When comparing the amount of land needed for units of energy, the study found that beef required 31 times the land area of the the equivalent quantity of grain.

The large variations seen above highlight the difficulties in estimating amounts of land required for personal food production. Estimations of how much food is eaten per capita, multiplied by population, gives a good estimate of requirement, but accurately calculating the area required to produce that amount of food, or how much food can be produced in a finite area, is more complex. (Colasanti & Hamm, 2010), (McLintock, Cooper, & Khandeshi, 2013), (Grewal & Grewal, 2012), (Peters, Bills, Lembo, Wilkins, & Fick, 2009).

## 2.4 EXISTING LAND USE

As well as establishing how much land is available for urban agriculture and how much land is required to feed a given population, it is also important to know how much land is already being used for food production, and where in the urban environment this land is located. GIS technology is an ideal means of acquiring information about where urban agriculture is being used. Web map technology, such as Google Maps, used in conjunction with GIS has seen the appearance of publicly-available maps locating community gardens for many cities around the world; this in turn informs people of where they can find space to grow food (CANMEN, 2013); (Neighborhood Farm Initiative, 2013); (Capital Growth, 2013).

GIS technologies can be used to answer important questions relating to food security in urban environments, and government agencies and authorities have been able to gain insight into how urban agriculture feeds into cities' wellbeing and economic activities by collecting quality data, and by answering questions such as:

*“Where are urban agricultural activities concentrated, and why? What kinds of crops are being grown? In what types of soil? By which groups within the urban population? How available is water and what is its quality? How far is it from farm to market? [and] Are there potential health and environmental risks?”*  
(Dongus & Drescher, 2006, p.4).

Maps of sites of urban agricultural activity can be used to identify gaps in the distribution of existing sites; areas where inhabitants have little access to food production sites can then be targeted. This can be

particularly important when in areas where there is low income and/or high levels of nutrition-related disease (Taylor & Lovell, 2012).

Remotely-sensed image analysis has been used to collect data on the extents of urban agriculture. Taylor and Lovell (2012) used manual interpretation of Google Earth imagery to collate datasets for the city of Chicago relating to community food gardens, urban farms, school gardens, single plot vacant lot gardens (of various size), and residential gardens (of various size). Classified image analysis didn't pick up the finer differences in patterns of vegetable gardens, so collecting the data manually, despite the fact it is time-consuming, enabled a more accurate picture of the extent of urban agricultural activity to be generated. Once the data was collected, it could be used, along with other GIS datasets such as census data, to perform spatial distribution analysis. Through this analysis it was possible to see how clusters of demographically different populations practiced urban agriculture, where more gardens were potentially required, and the substantial contribution made by "squatter gardens", which are constantly vulnerable to development.

Other studies were completed by Addo (2010), and Dongus & Drescher (2006), for Accra, Ghana, and Dar es Salaam, Tanzania, respectively. Using modern remote-sensing data collection techniques –such as automated image classification, manual digitisation and physical GPS surveys – it was possible to collect comprehensive data on where urban agriculture was being practiced, along with other information such as crop varieties and numbers of workers. This information was deemed to be valuable in areas of rapid urbanisation, in areas where a lack of management was resulting in pollution, and in areas of stagnant water which served as breeding grounds for malaria-carrying mosquitoes. By creating quality geospatial datasets, awareness can be raised, which in turn allows for better management policies to be developed and implemented.

Geospatial information on urban and periurban agriculture was used by Kremer & DeLiberty, (2011) who conducted spatial analysis of urban agriculture when researching the local food system in Philadelphia. They combined the urban food system data with census data in order to arrive at a better understanding of

the urban food system. The spatial analysis showed that the majority of community gardens were located in lower income areas, and the majority of farmers' markets were located in areas with higher income. Where markets were located in lower income areas, they were often near institutions such as universities or hospitals which were supporting them, or being run by specific programs aimed at improving food access to specific areas.

## **2.5 ACCESSIBILITY**

Urban food accessibility is well-researched, particularly in health sciences literature. Studies around nutrition-related diseases such as diabetes, heart disease, and obesity, have given rise to research into the availability of healthy food in cities, and in particular people's ability to access supermarkets and farmers markets to purchase healthy food. Food deserts – areas lacking easy access to healthy nutritious food – have been identified in many North American cities. Food deserts are often linked to socio-economic and cultural differences within these cities (Beaulac, Kristjansson, & Cummins, 2009); (Walker, Keane, & Burke, 2010); (Larson & Gilliland, 2008).

In light of peak fuel, and as living with a declining energy source takes on a greater significance in everyday life, the use of private vehicles will undoubtedly become more expensive, and more people will be unable to afford the luxury of private transport. As oil prices increase, and therefore the cost of transporting food increases, it is probable that we will see a further rise in the cost of imported foods (Oil Price, 2014). This will have a two-fold effect on people's access to healthy food: firstly, by increasing the cost of food, and secondly, by increasing the cost of travel to reach food stores or markets. When it comes to accessibility of fresh healthy food, more sections of the population will likely find themselves in a food desert situation (Peak Oil, 2011).

As well as purchasing from food stores or markets, healthy food can be accessed by growing food on private property or in community gardens. Several systems have been created for identifying ideal locations for the new community gardens that are needed to alleviate the lack of fresh food within



cities (Longcore, Lam, Seymour, & Bokde, 2011); (Kremer & DeLiberty, 2011); (Metcalf & Widener, 2011). These studies have taken the carrying capacity of these community gardens into account, but the question of accessibility to the gardens has been left answered.

Private car ownership has been claimed to be a factor in access to healthy food; when living in food desert areas, people are often required to walk long distances or use public transport to get to supermarkets. Although this in itself is not a major issue, the return trip on foot carrying large quantities of food may prove to be a significant issue. Also, regular trips to convenience stores are often required to ‘top up’ on groceries where fresh healthy food may be unavailable or expensive (Coveney & O'Dwyer, 2009); (Metcalf & Widener, 2011).

As fuel price increases, the use of active mode travel, i.e., either walking or cycling, will become commonplace, particularly if fuel price increases push the cost of public transport up. It is of great importance that people have access to healthy food within a reasonable distance of their homes.

The USDA's report entitled ‘Access to Affordable and Nutritious Food’ (2009) categorises walkable access to food as “...high, if a supermarket is within a half mile; medium, if a supermarket is between one-half and one mile; and low, if the nearest supermarket is more than a mile away” (pg. 132). The report notes that there are other factors that may need to be taken into account such as an individual's capability, and the safety of the journey (both in terms of road safety and crime). The distances used were taken from a literature review in which several studies were cited as having similar distances.

Another mode of active transport that is taken into account in accessibility studies is cycling. Unwin (1995) makes the assumption that all journeys of 5km or less are within a reasonable cycling distance for adults aged over 15 years.

A community garden can only produce a finite amount of food, and therefore can only cater to a finite number of people, not necessarily the entire population within the maximum travel distance. This is particularly apparent in areas with high population densities, such as areas with apartment buildings.

Both food retailers and food producers play an integral part in supplying food to the urban population; this study will take access to both potential food growing space and food retailers into account when measuring resilience to food insecurity in the urban environment.

### 3 METHODOLOGY

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An integrated approach has been developed in this study to investigate questions used in previous research into how much land is available and how much land is required. This integrated approach also incorporates a measure of accessibility, both to potential food growing space and to food retailers. The identification, ownership, and relative location of potential growing space to residential property are all taken into account. Accessibility is measured at the household level, allowing the attribution of a ‘resilience to food insecurity’ category for each household.

This section describes the GIS-based methodology that has been developed in this study. The methodology can be used for any city, and is designed to enable the visualisation, through maps and graphs, of the impact of accessibility to food growing space and food stores on resilience to food insecurity at a household level. This chapter details the data requirements and the data processing procedures required to use this methodology.

Figure 2 shows a generalised view of the process used in the methodology; following this process allows each household to be placed within one of six resilience categories. The methodology is described in more detail below.

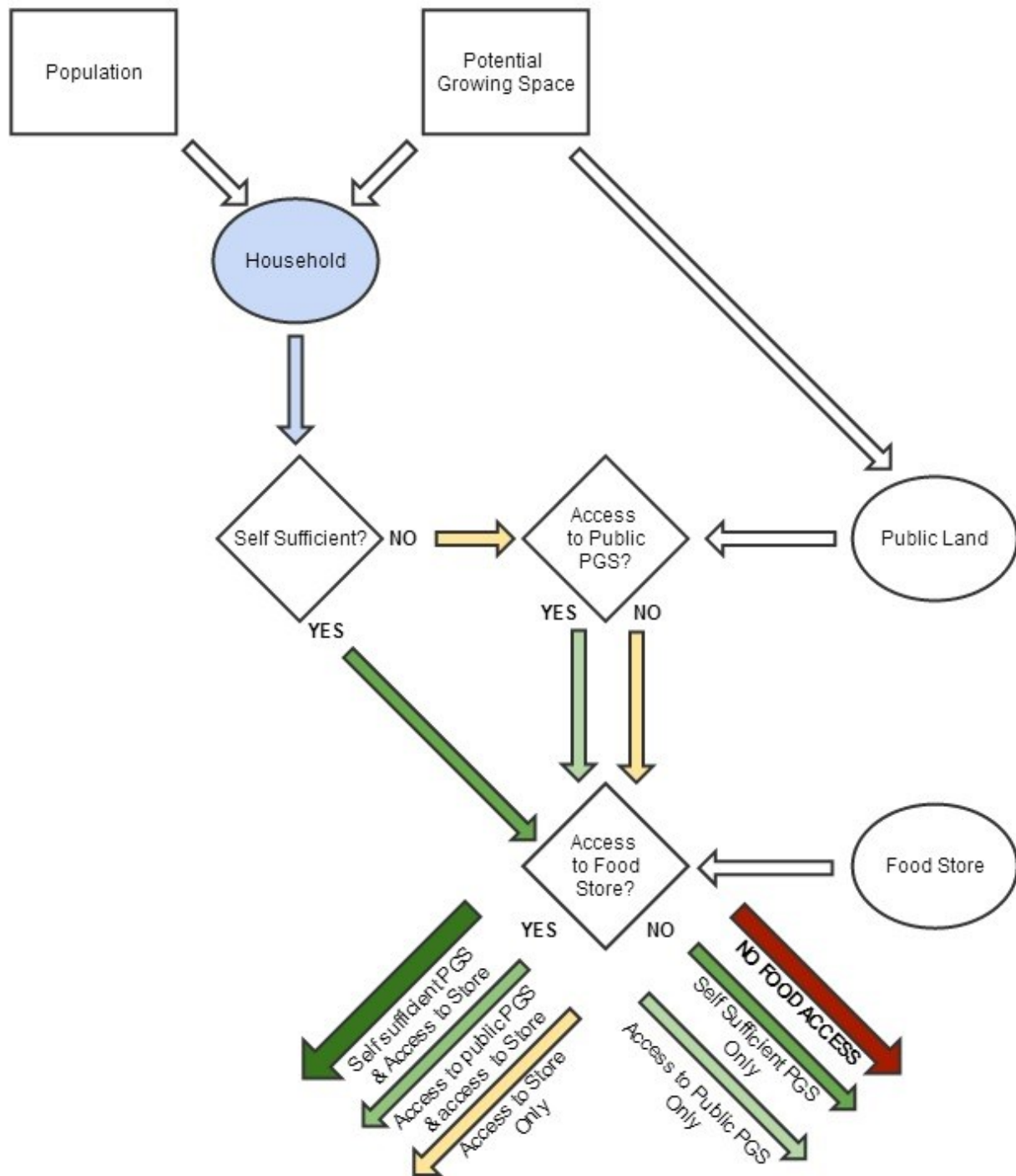


Figure 2 Generalised methodology process diagram

### 3.1 DATA REQUIREMENTS

The first stage of the method is data collation. Depending on availability, data may be acquired from government or private agencies or collected as part of the study; the datasets are considered to be [non]-standard. The term [non]-standard data is used in this study to refer to datasets that are normally considered to be standard datasets, such as property parcels, road centrelines, census area blocks and planning zones. These [non]-standard datasets are usually collected and administered by government agencies such as councils, or national land information or statistics offices. The prefix [non] is used to highlight the fact that even though these datasets are ubiquitous, they are often very different in structure.

The structural differences in the data not only occur in the datasets belonging to different countries but also between local territorial authorities. For example, in New Zealand, each Territorial Authority (TA) (City or District Council) is responsible for the District or City Plan. The plan includes rules on what landowners are permitted to do, depending on where their land is located. As part of the District or City Plan, zone maps are included to show where these rules apply. There are commonly used zones for commercial, industrial and residential land; however, depending on each TA, other zones may also be included, and the three zones mentioned above may be broken down further into smaller sub-zones.

When attempting to add data to a fixed model structure it is important that the input data is in a standard form. In this study, a standard data schema for the spatial data set is used. The standardised schema allows data from any source to be manipulated into a standard form for the purposes of following the methodology used in this research (Appendix 8.1). Standardised data schemas have been used recently in the ArcGIS for Local Government toolset (ESRI, 2014), the Urban Observatory project (Urban Observatory, 2013) and Canterbury Maps (Environment Canterbury, 2013) to allow the integration of data from many sources to be used in a single modelling environment. The importance of a standardised schema becomes even more apparent when using data from different countries, as not only does the model structure have to deal with structural differences in the data but also linguistic differences.

The following [non]-standard datasets have been used in the methodology developed in this study:

<b>Dataset</b>	<b>Data type</b>	<b>Description</b>
<i>Property boundaries</i>	Polygon	Lot or Title area of the property. This will represent the household unit.
<i>Population</i>	Points (household) or Polygon (CAU)	Household population data if available, or household population derived from census area units.
<i>Planning Zones</i>	Polygon	Residential zones from city or district plan zone data.
<i>Publicly owned land</i>	Polygon	As property boundary dataset, this should include all publicly owned, or government-administered land.
<i>Potential growing space (PGS)</i>	Polygon	Space considered to be useable for growing food. This could be derived from and/or include; NDVI, land cover, soil types, slope, aspect etc.
<i>Road network</i>	Line	The road network is used to define distances between households and destinations. The network could also include walking and cycling paths if available.
<i>Retail store locations</i>	Point	Dataset comprised of supermarkets, farmers' markets and grocery stores. Only stores that offer a full complement of foods required for a healthy diet should be included.
<i>Area required</i>	Variable	The amount of growing space required per person.
<i>Maximum travel distance</i>	Variable	The maximum distance the householder is willing/able to travel.

*Table 1. Datasets used in methodology*

It is important to take into account the ownership of land, which determines how much land is available to the private landowner and how much land could be potentially available for public use. The inclusion of all vacant land for food production can be misleading, as the longevity of any food production activity is unknown and subject to owners' and/or developers' goodwill.

This research methodology assumes that any private land is to be used by the owner, either for personal use, for lease, or for potential commercial growing; therefore private vacant land will be dealt with in the same way as any other private land.

For the purposes of this study, public land is categorised as land owned or administered by the government or equivalent. Public land may include areas such as parks and reserves, river and coastal esplanades, and land around government buildings.

## **3.2 DATA PRE-PROCESSING**

### **3.2.1 Potential Growing Space**

The first stage of the methodology involves creating the *Potential Growing Space (PGS)* dataset; this may involve combining several datasets, or making a selection from a single dataset. If more than one dataset is used, the different datasets will need to be combined into a single dataset that can be used in the different stages of the methodology. A standard data schema has been employed for the purposes of consistency (Appendix 8.1).

### **3.2.2 Households**

The *Households* data set is created from a combination of the following input data sets; *property boundaries*, *population*, *potential growing space* and *area required*.

1. The *property boundaries* are used as a base to which the *population* is added.
2. By multiplying the *area required* figure by the *population*, it is possible to gain a household level *growing space requirement*.
3. The dataset is then combined with the *potential growing space (PGS)* dataset, making it possible to calculate the total size of the property, and the amount of available growing space on the property.
4. An *external space requirement* is calculated by subtracting the *available space* from the *required space*.
5. Two extra field are added, one for an *Access to PGS* category and one for an *Access to Food Retailer*.

6. A final field is added for the *Household Resilience* category, this will be derived from the combination of of the *Access to PGS*, and *Access to Food Retailer* categories.

The final *Household* dataset attributes include:

- Household ID
- Total property area
- Population
- PGS required
- Available PGS
- External PGS required
- Access to PGS
- Access to Food Retailer
- Household Resilience

### 3.2.3 Public Land

The *Public Land* dataset is created from a combination of the *publicly-owned land*, and *potential growing space* datasets. By combining these datasets, it is possible to calculate the total area and the *available growing space*.

The final *Public Land* dataset attributes include:

- Public Land ID
- Total area
- Available PGS

## 3.3 GEO-PROCESSING

The geo-processing is run in two stages, firstly, to determine the accessibility of potential growing space and, secondly, to determine the accessibility of food retailers. The results are then combined to produce a single dataset.



### 3.3.1 Accessibility of Potential Growing Space

When it comes to access to *potential growing space* (PGS), households are divided into three broad categories; *self-sufficient*, *access to public PGS*, and *no access to PGS*. These categories are used in the Household attribute table's *Access to PGS Category* field.

Prior to using any tools, it is possible to gain initial results for *self-sufficient* households. All households with a negative value in the *External PGS Required* field have enough, or more than enough PGS to provide for the *Household* population. These households are labelled as *self-sufficient* in the *Access to PGS Category* column of the attribute table. Excess space available on private property is not considered available to others in this research, as it is assumed that this space could be used for commercial food growing if desired.

A network analysis is then performed to measure household accessibility to potential growing space for the non *self-sufficient* households. Using a capacitated location-allocation method, it is possible to allocate available space from *Public PGS* to the nearest households until the capacity of each public land parcel is reached. Once the capacity is reached, no more households will be allocated space even if they are within the maximum travel distance.

Several important variables are required to execute the capacitated location-allocation analysis, these are: *demand weight*, *impedance cut-off*, and *facility capacity*. In this instance, the *demand weight* is the amount of *external PGS required* per household, the *impedance cut-off* is the *maximum distance to be travelled*, and the *facility capacity* is the amount of *available PGS* within each *Public Land* parcel.

### 3.3.2 Accessibility of Food Retailers

To measure accessibility of food retailers to households, the nearest facility method of the network analyst tools was used. It was assumed that the nearest food retailer to each household would be able to acquire enough stock to fulfil the needs of the total allotted household populations.

The *maximum travel distance* value is used to determine how far household residents can travel to a food retailer. All households that fall within the defined distance will be labelled as *access to food retailer* in the *Access to Food Retailer Category* column of the *Household* attribute table. All other households will be labelled *no access to food retailer*.

### 3.3.3 Household Resilience Categories

Once the network analysis is complete, household resilience categories can be calculated from the *access to PGS*, and *Access to Food Retailer* category attributes as follows in Table 2:

<b>Access to PGS</b>	<b>Access to Food Retailer</b>	<b>Resilience Category</b>
Self-sufficient	Access to food retailer	Self sufficient with access to food retailer
Self-sufficient	No access to food retailer	Self sufficient but no access to food retailer
Access to Public PGS	Access to food retailer	Access to public PGS with access to food retailer
Access to Public PGS	No access to food retailer	Access to public PGS but no access to food retailer
No access to PGS	Access to food retailer	No access to PGS but access to food retailer
No access to PGS	No access to food retailer	No access to food

*Table 2. Household resilience categories*

No hierarchical values have been attributed to the resilience categories, other than *Self-sufficient with access to food retailer* offering the most resilient position and *No access to food* being the least resilient; it is difficult to put a measure on which of the other categories can be considered more or less resilient. Each category has access to food to cater for the population of the household either from growing space or from a food retailer, and it may come down to the householder's personal preference as to which is most appropriate for their needs.

These categories are used to show results in a map format and/or a graphical format, both of which allow for information to be seen at a glance. Using maps makes it easy to identify clusters of households which are considered to be more or less resilient to food insecurity, and the tables offer an easy to view breakdown of percentages of households in each category.

### **3.4 CASE STUDY METHODOLOGY**

This research uses two case studies, Christchurch and Stockholm, to demonstrate the methodology outlined above. The significant differences between both the built environments and the spatial data structures of these cities make them useful as case studies for illustrating how different cities can use the methodology to gain insight into their resilience to food insecurity. The data acquired from each country required varying degrees of pre-processing which will be described in this section.

#### **3.4.1 Christchurch, New Zealand**

Christchurch is located on the east coast of the South Island of New Zealand, has a population of 348,435 (2006 census, Statistics New Zealand, 2014) and covers an area of 45,240 hectares.

### 3.4.1.1 Christchurch – Data sets

The datasets were collected from a variety of sources as shown in Table 3 below.

Dataset	Source
Property boundaries (Polygon)	Land information New Zealand ( <a href="http://data.linz.govt.nz">http://data.linz.govt.nz</a> ). <i>NZ property titles including owners.</i>
Population	Statistics New Zealand ( <a href="http://www.stats.govt.nz/">http://www.stats.govt.nz/</a> ). 2006 Census population data and mesh block boundaries.
Residential (Living) Zones	Christchurch City Council ( <a href="http://www.ccc.govt.nz">www.ccc.govt.nz</a> ). Planning zones from The City Plan, June 1995.
Public Land	Land information New Zealand ( <a href="http://data.linz.govt.nz">http://data.linz.govt.nz</a> ). <i>NZ property titles including owners.</i> This dataset includes property title boundaries and ownership information. The ownership information was used to split publicly and privately owned land.
Potential Growing Space (PGS)	Land information New Zealand ( <a href="http://data.linz.govt.nz">http://data.linz.govt.nz</a> ). NDVI dataset derived from KiwiImagery (Crown Copyright Reserved) 2.4m multispectral imagery. The imagery was classified using the NDVI function in ArcGIS 10.1. The data was then reclassified to include only pixels with a value $\geq 0.2$ to give a representation of land with bare soils and vegetation.
Road Network	Land information New Zealand ( <a href="http://data.linz.govt.nz">http://data.linz.govt.nz</a> ). <i>NZ Road Centre line.</i>
Retail Store Locations	zenbu.co.nz ( <a href="http://www.zenbu.co.nz/">http://www.zenbu.co.nz/</a> ) “...a collaboratively edited directory of businesses and places...”

Table 3. Data used in Christchurch case study

To demonstrate how different input variables can have an impact on the final results, three different values were used for the *Area required* variable and two different values were used for the *Maximum travel distance* variable. These can be seen below in Table 4.

Area required (to grow enough food for one person).	70m <sup>2</sup> Absolute minimum of arable land (FAO, 1993) 372m <sup>2</sup> Biointensive (intermediate yields) (Jeavons, 2002) 650m <sup>2</sup> Conventional techniques (Vegan) (Jeavons, 2002)
Maximum travel distance	1km Reasonable walking distance (USDA, 2009) 5km Reasonable cycling distance (Unwin, 1995)

Table 4. Variables used in Christchurch case study

### 3.4.1.2 Christchurch - Data pre-processing – Household

To prepare the Christchurch *Household* dataset, the following datasets were used; NZ property titles including owners, mesh block and average population from NZ census 2006; residential zones from the Christchurch City Plan; and the NDVI dataset.

1. All privately-owned property was selected from the property title data (LINZ primary parcel data is available with owner information, it was therefore possible to select just privately-owned properties to create the *Household* feature class).
2. Of these properties, those within the residentially zoned areas (Figure 3) were reselected.

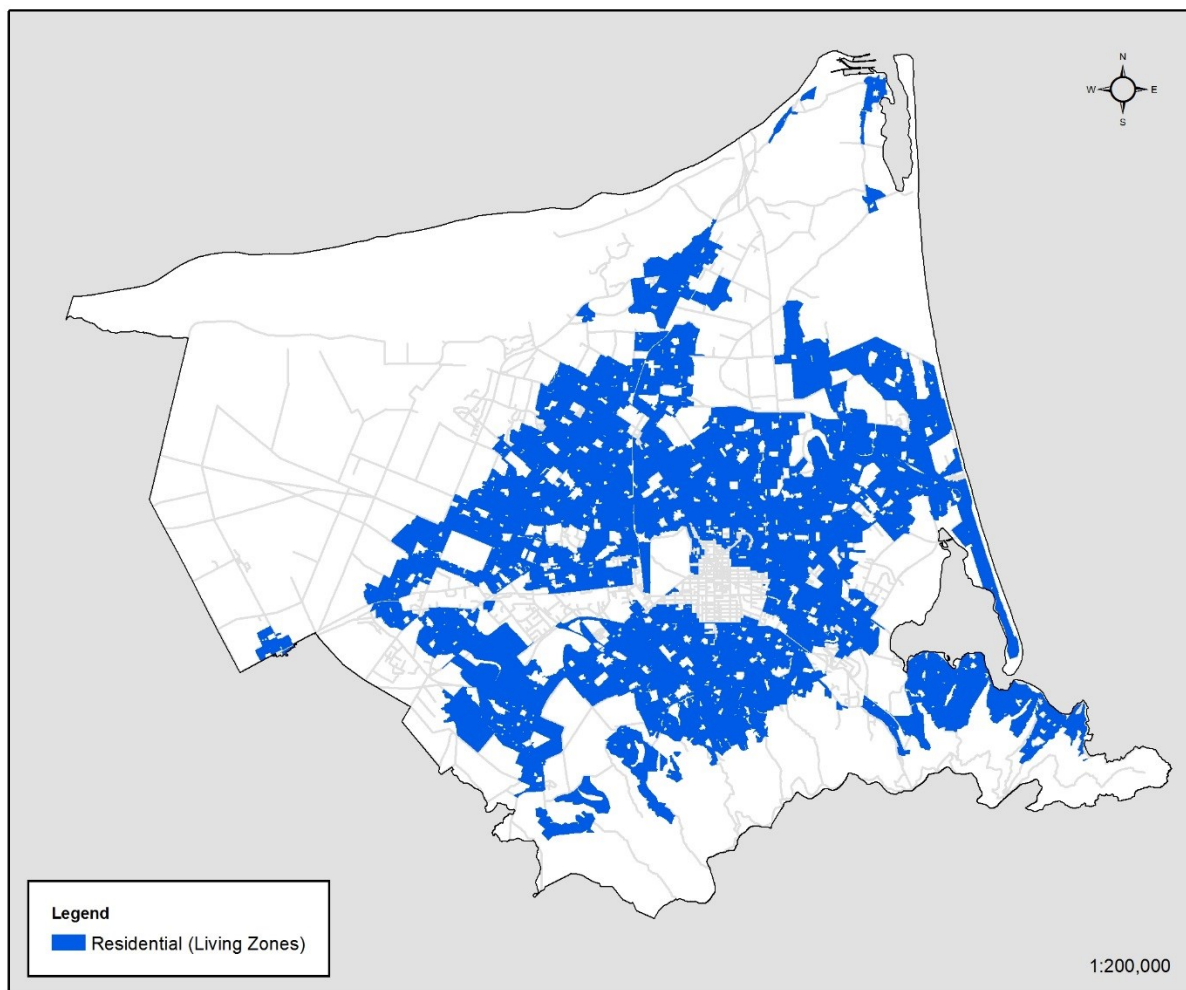


Figure 3. Residential zones in Christchurch

3. The private residential properties were then attributed the the average household population value for the mesh block that they were within.
4. A field for *required space* was added and calculated by multiplying the population by the *area required* variable (this was recalculated each time the variable value was changed).
5. The *Household* data was intersected with the *PGS* (Figure 4) to give a measurement of *Available PGS* per household.

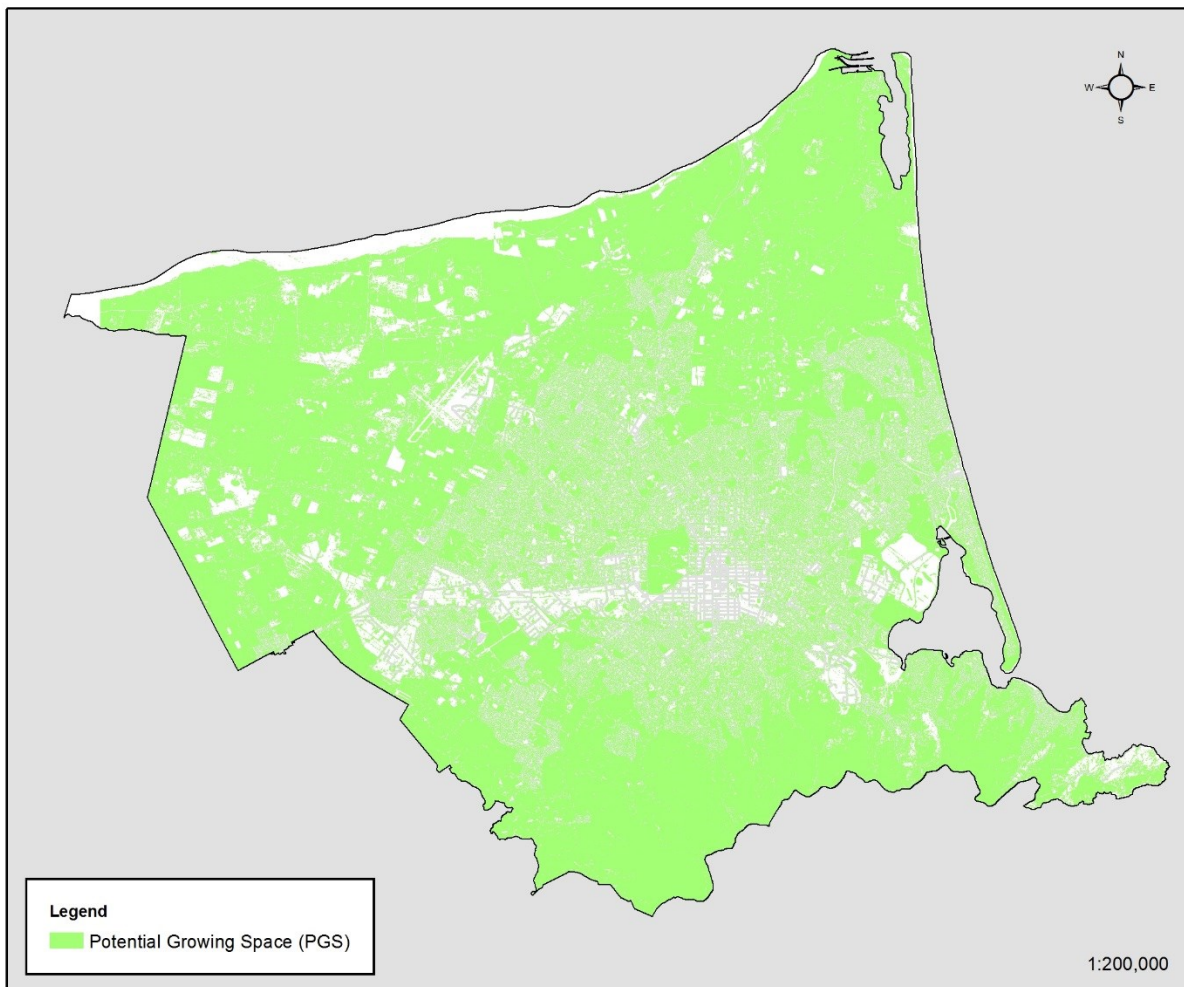


Figure 4. Potential growing space (PGS) in Christchurch

6. The household *External PGS requirement* was calculated by subtracting the *Available PGS* from the *Required PGS*.

#### **3.4.1.3 Christchurch – Data pre-processing – Public Land**

The *Public land* data set for Christchurch was also derived from the *NZ property titles including owners* and the NDVI dataset.

1. From the *LINZ property titles including owners* dataset, a selection of all land owned by *Christchurch City Council* or *Her Majesty the Queen* was created. This land was assumed to be publicly owned for the purposes of this research. This selection was used to create the *Public Land* feature class (Figure 5).
2. Parcels with an average length or width of less than 10 metres were removed from the selection as these were considered to be too small to be worthwhile productive food growing areas for the purposes of this case study.

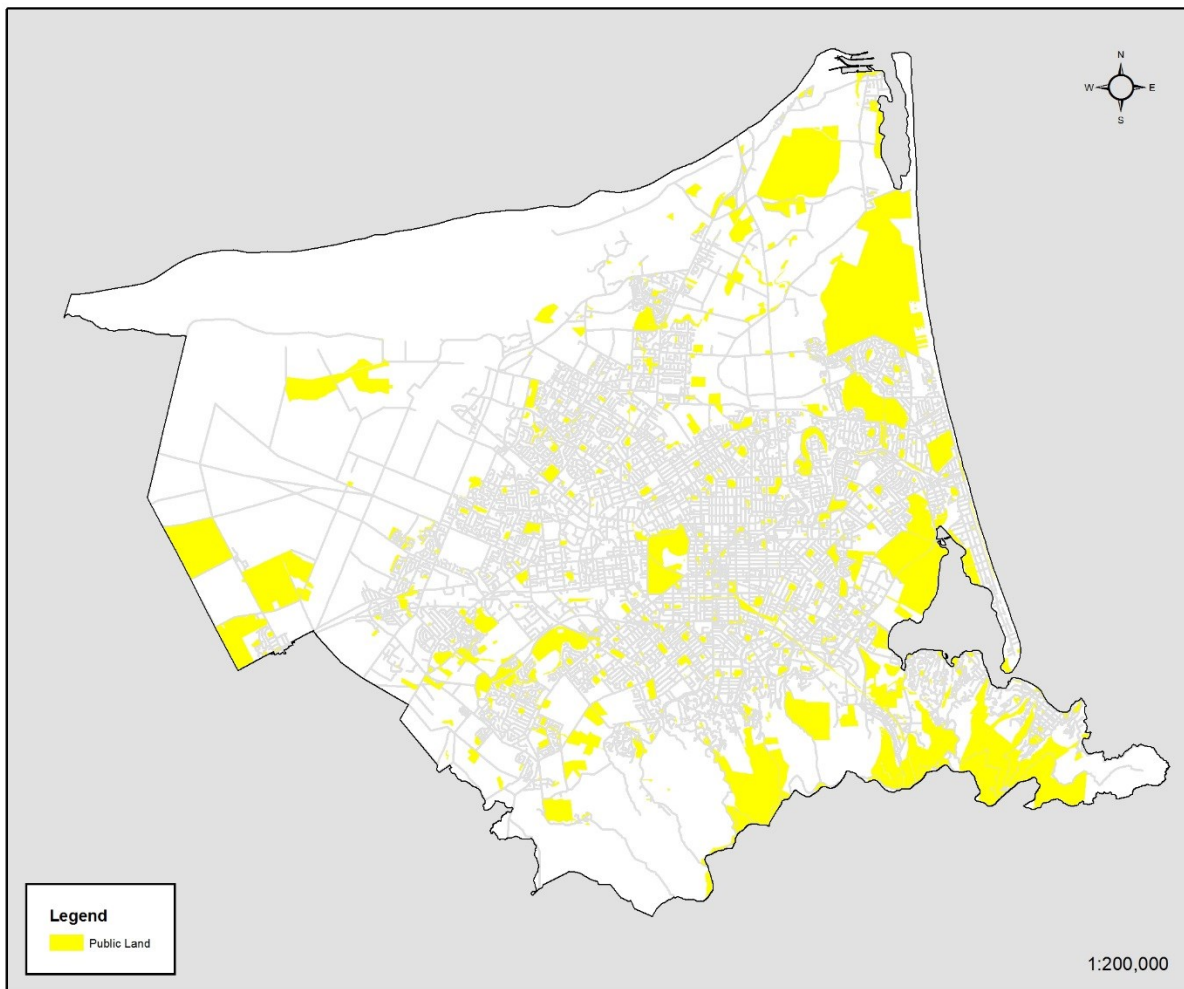


Figure 5. Public land in Christchurch

3. The *public land* feature class was intersected with the *PGS* data (Figure 4), which enabled the calculation of *Available PGS* on all *public land* parcels.

#### 3.4.1.4 Christchurch - Accessibility of PGS

The capacitated location-allocation method of the network analysis toolset in ArcGIS 10.1 was used to calculate the nearest available PGS to each household.



1. All *households* with a negative value in the *External PGS required* field were selected and labelled *self-sufficient* in the *Access to PGS* field.
2. Only non *self-sufficient* households were included in the network analysis.
3. The capacitated location-allocation method requires three important variables; the *demand weight*, the *impedance cut-off*, and the *facility capacity*. The values used can be seen in Table 5.

Variable	Value	Data Location
Demand Weight	<i>External PGS Required</i>	<i>Household</i>
Impedance Cut-off	<i>Maximum Travel Distance</i>	<i>Input variable</i>
Facility Capacity	<i>Available PGS</i>	<i>Public Land</i>

*Table 5. Capacitated location-allocation input values for Christchurch*

4. The location-allocation analysis results enable the *Access to Public PGS* category label to be added to the *Access to PGS* field to be assigned to the features which were within the distance and were allocated space within the *Public land*.
5. The remaining households were assigned the *no access to PGS* category label.

### 3.4.1.5 Christchurch - Accessibility to Food Retailers

The *closest facility* method from the network analyst toolset was used to measure accessibility to food retailers.

1. The selection of food retailers included fresh fruit and vegetable stores, grocery stores, and supermarkets.

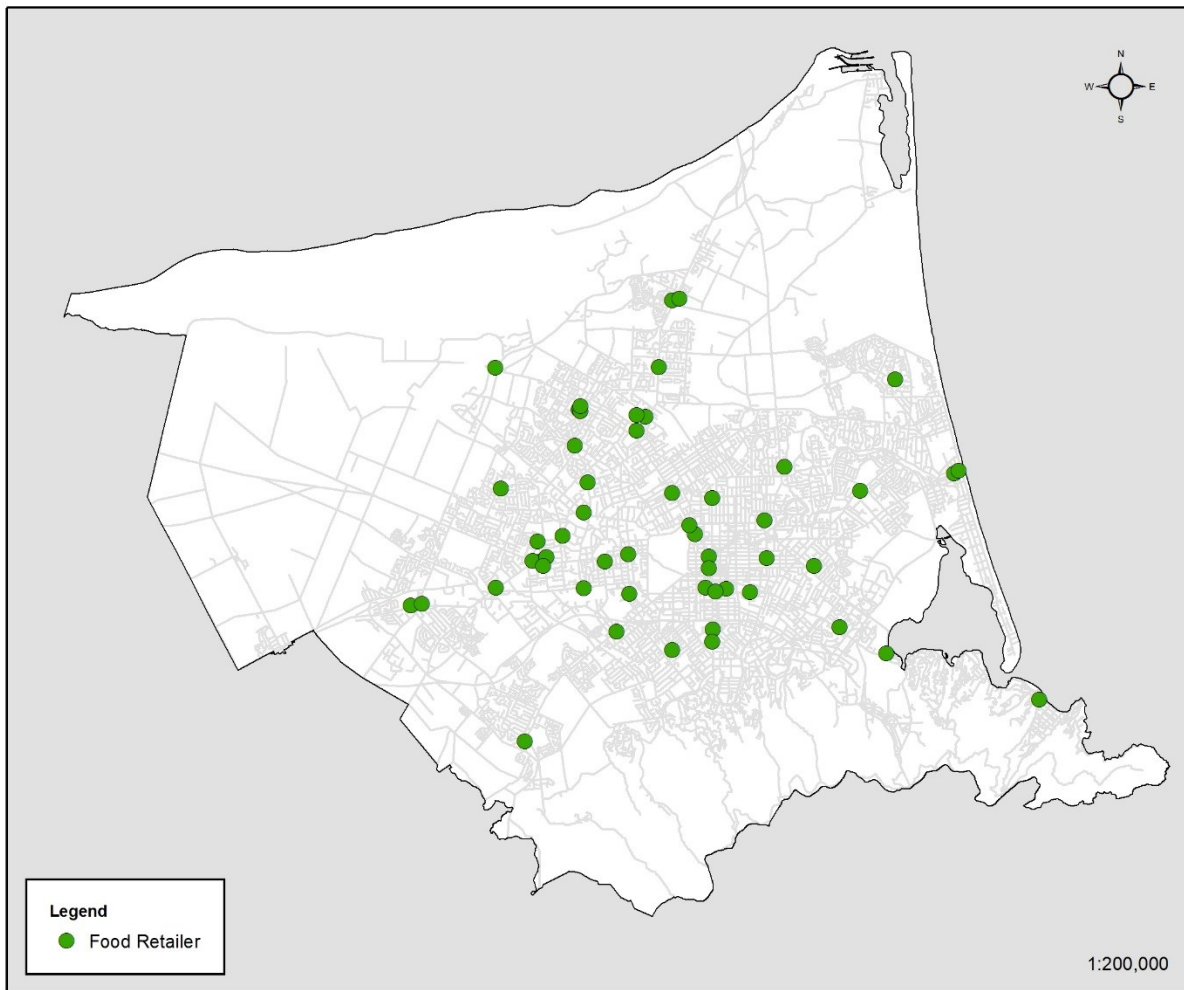


Figure 6. Food retailer locations in Christchurch

2. The *closest facility* method from the network analyst toolset required three input variables, these included the following as shown in Table 6.

Variable	Value	Data Location
Facilities	<i>Food retailer (point)</i>	<i>Food retailer</i>
Demand locations	<i>Household (centroids)</i>	<i>Household</i>
Impedance cut-off	<i>Maximum travel distance</i>	<i>Input variable</i>

*Table 6. Input variables for closest facility network analysis for Christchurch*

3. The *Household* dataset was converted to centroid points for the analysis, the results were then transposed back to the original polygon feature class.
4. The *impedance cut-off* was adjusted for each input variable for reasonable walking and cycling distances.
5. Once the analysis was complete all *households* within the *impedance cut-off* were labelled in the *Access to Food Retailer* column of the *Households* attribute table as *Access to food retailer* and the remaining were given the label *No access to food retailer*.

#### **3.4.1.6 Christchurch - Household Resilience categories**

Once the network analyses were complete, the household resilience classes were calculated by combining the *Access to PGS* and *Access to Food Retailer* categories as described in section 3.3.3.

### 3.4.2 Stockholm, Sweden

Stockholm is located midway along the east coast of the Sweden, the Wider Stockholm County has a population of 2,163,042 (Statistics Sweden, 2014). The City of Stockholm (used in this case study) has a population of 897,700 and covers an area of 20,900 hectares (Stockholm Stad, 2013).

#### 3.4.2.1 Stockholm - Datasets

As with Christchurch, the datasets were collected from a variety of sources – see Table 7 below.

Dataset	Source
Property boundaries (Polygon)	Lantmäteriet Fastighetskartan ( <a href="http://www.lantmateriet.se">www.lantmateriet.se</a> ) – shows property division from the Cadastral map.
Population	Sweden Census 2010 ( <a href="http://www.scb.se">http://www.scb.se</a> ) Sweden Census Area Units (CAU) and 2010 Census data for CAU population.
Residential (Living) Zones	Stockholm City Council ( <a href="http://international.stockholm.se/Future-Stockholm/Stockholm-City-Plan">http://international.stockholm.se/Future-Stockholm/Stockholm-City-Plan</a> ) <i>Gles stadsbebyggelse</i> (Sparse urban development) and <i>Tät stadsbebyggelse</i> (Dense urban development) zones.
Public Land	Stockholm City Council ( <a href="http://international.stockholm.se/Future-Stockholm/Stockholm-City-Plan">http://international.stockholm.se/Future-Stockholm/Stockholm-City-Plan</a> ) <i>Park/Grönt</i> (Nature, park, large sports area, cemetery etc.) No ownership data was available for this research. It was assumed that all parks in this dataset were owned or administered by the Swedish Government.
Potential growing space (PGS)	Biotokarta ( <a href="http://miljobarometern.stockholm.se/content/docs/tema/natur/biotopkarta_2009_publ.pdf">http://miljobarometern.stockholm.se/content/docs/tema/natur/biotopkarta_2009_publ.pdf</a> ) <i>Odlings mark</i> (Cultivation soil) <i>Frisk gräsmark</i> (Fresh grassland) <i>Fuktig gräsmark</i> (Damp grassland) <i>Torr gräsmark</i> (Dry grassland)
Road Network	Lantmäteriet Vägkartan ( <a href="http://www.lantmateriet.se">www.lantmateriet.se</a> ) Sweden Road map
Retail store locations	Open Street Map ( <a href="http://www.openstreetmap.org">http://www.openstreetmap.org</a> )

Table 7. Data used in Stockholm case study

As with the Christchurch case study, three values were used for the *Area required* variable and two values were used for the *Maximum travel distance* variable. These can be seen below in Table 8.

Area required (to grow enough food for one person).	70m <sup>2</sup> Absolute minimum of arable land (FAO, 1993) 372m <sup>2</sup> Biointensive (intermediate yields) (Jeavons, 2002) 650m <sup>2</sup> Conventional techniques (Vegan) (Jeavons, 2002)
Maximum travel distance	1km Reasonable walking distance (USDA, 2009) 5km Reasonable cycling distance (Unwin, 1995)

*Table 8. Variables used in Stockholm case study*

### **3.4.2.2 Stockholm - Data pre-processing – Household**

To prepare the Stockholm *Household* dataset, the following datasets were used; *Lantmäteriet Fastighetskartan* (cadastral property boundaries), census area units (CAU) and CAU total population, sparse and dense urban development zones from the Stockholm City Plan, and the Biotope land cover dataset.

1. No ownership data was available for the Stockholm case study. All road parcels and presumed non-residential parcels were removed from the cadastral boundaries dataset. The remaining parcels were used to create the *Households* feature class data set.
2. Of these properties, those within the *Residential Zones* (Figure 7) were reselected, the remainder were removed from the dataset.

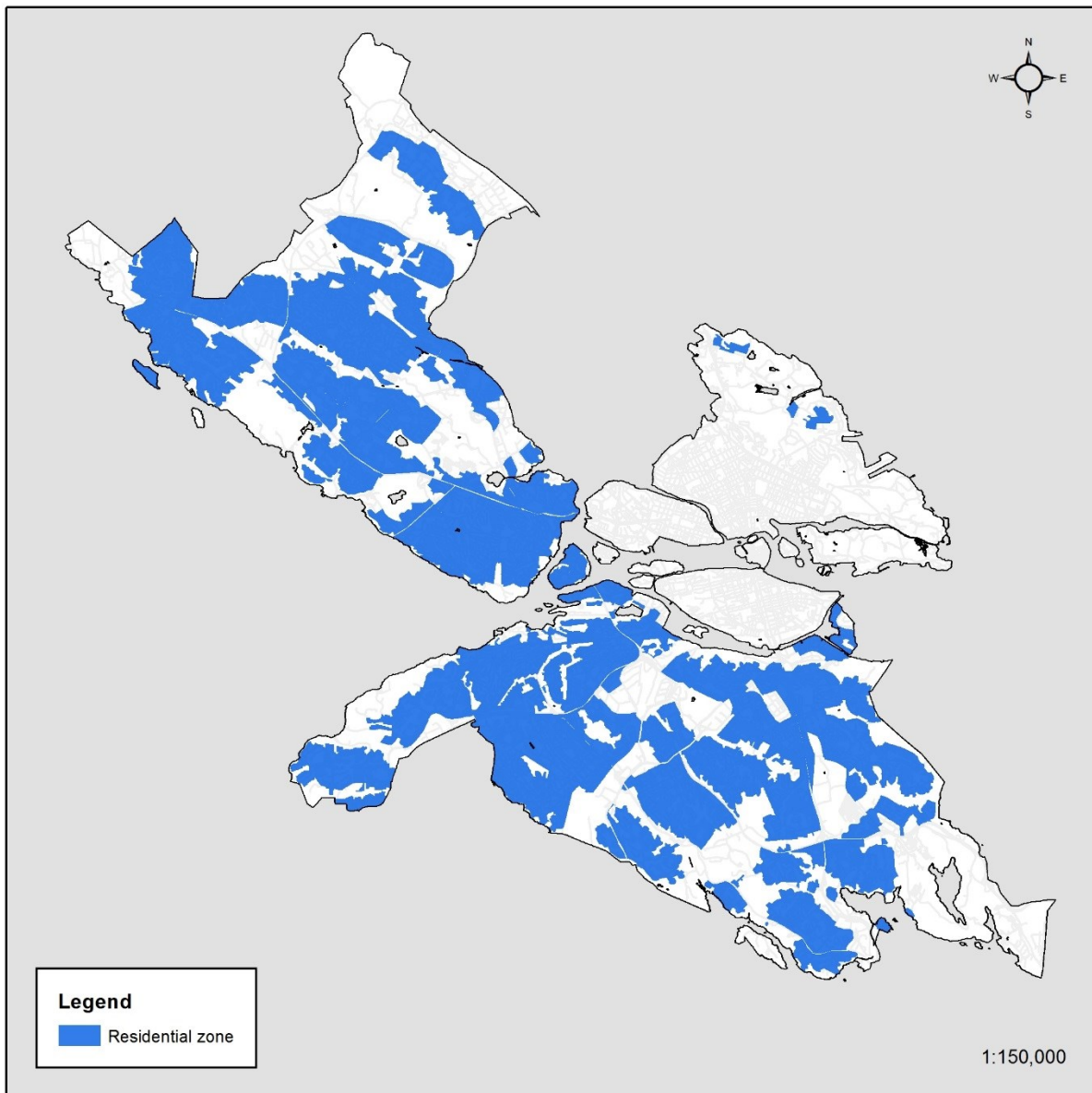


Figure 7. Residential zones in Stockholm

3. The *Household* features were then attributed the the average household population value for the census area unit that they were within. As the Swedish CAUs use a total population figure, the average population was calculated by dividing the total population by the count of *Households* within each CAU.

4. As in the Christchurch case study, a field for *required space* was added and calculated by multiplying the population by value from the *area required per person* variable. This was recalculated each time the value was changed.
5. The *Household* data was intersected with the *PGS* (Figure 8) to give a measurement of *Available PGS* per household.

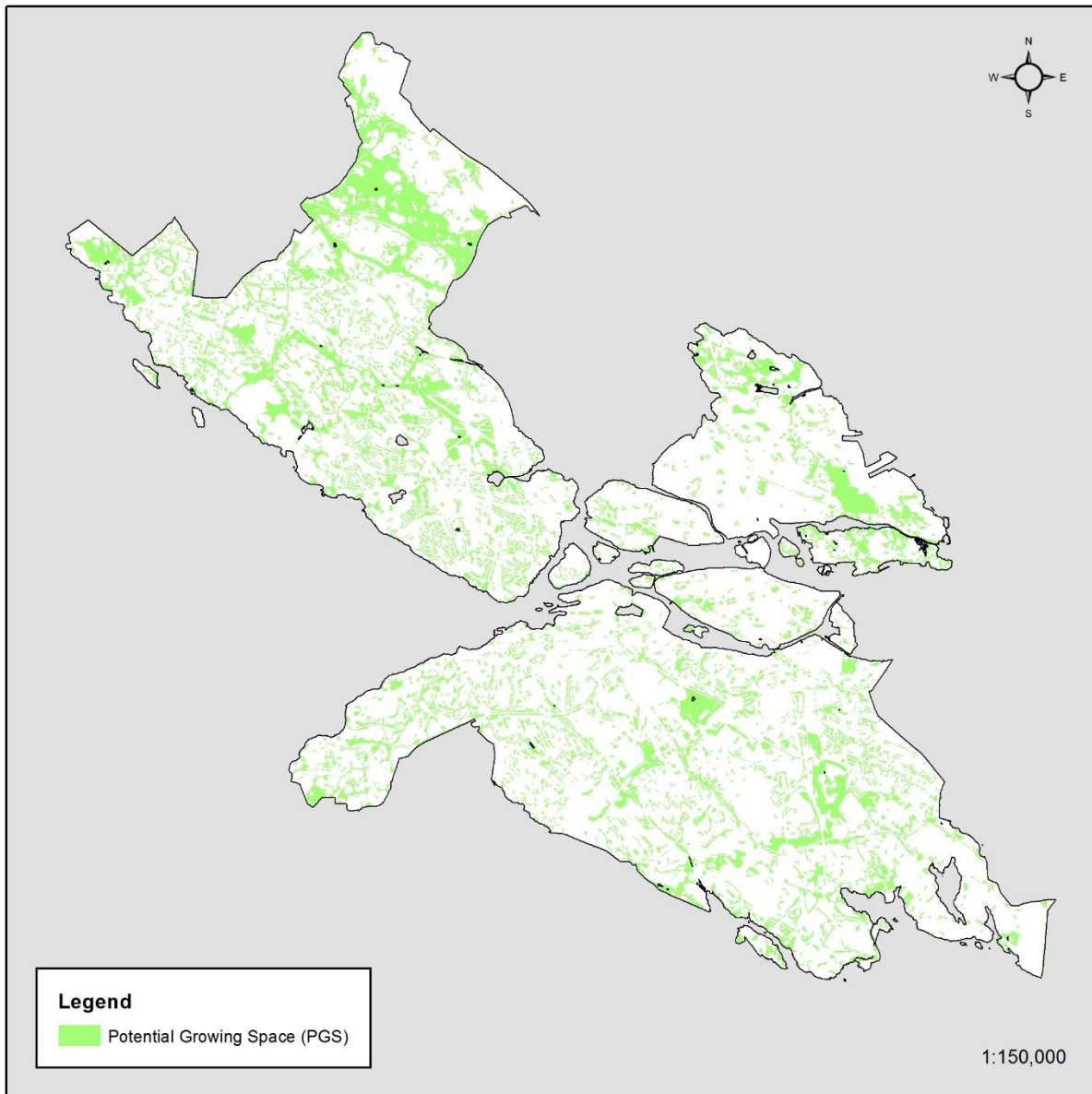


Figure 8. Potential growing space (PGS) in Stockholm

6. The household *External PGS requirement* was calculated by subtracting the *available PGS* from the *required PGS*.

#### **3.4.2.3 Stockholm - Data pre-processing – Public Land**

The *Public land* data set for Stockholm was derived from the *Park/Grönt* (nature, park, large sports area, cemetery etc.) zones from the Stockholm City Plan combined with the *PGS* data set.

1. As no ownership information was available for the Stockholm case study, for the purposes of this research the *Park/Grönt* zones were assumed to be government owned or administered and therefore assumed to be public land. This dataset was used to create the *Public Land* data set (Figure 9).



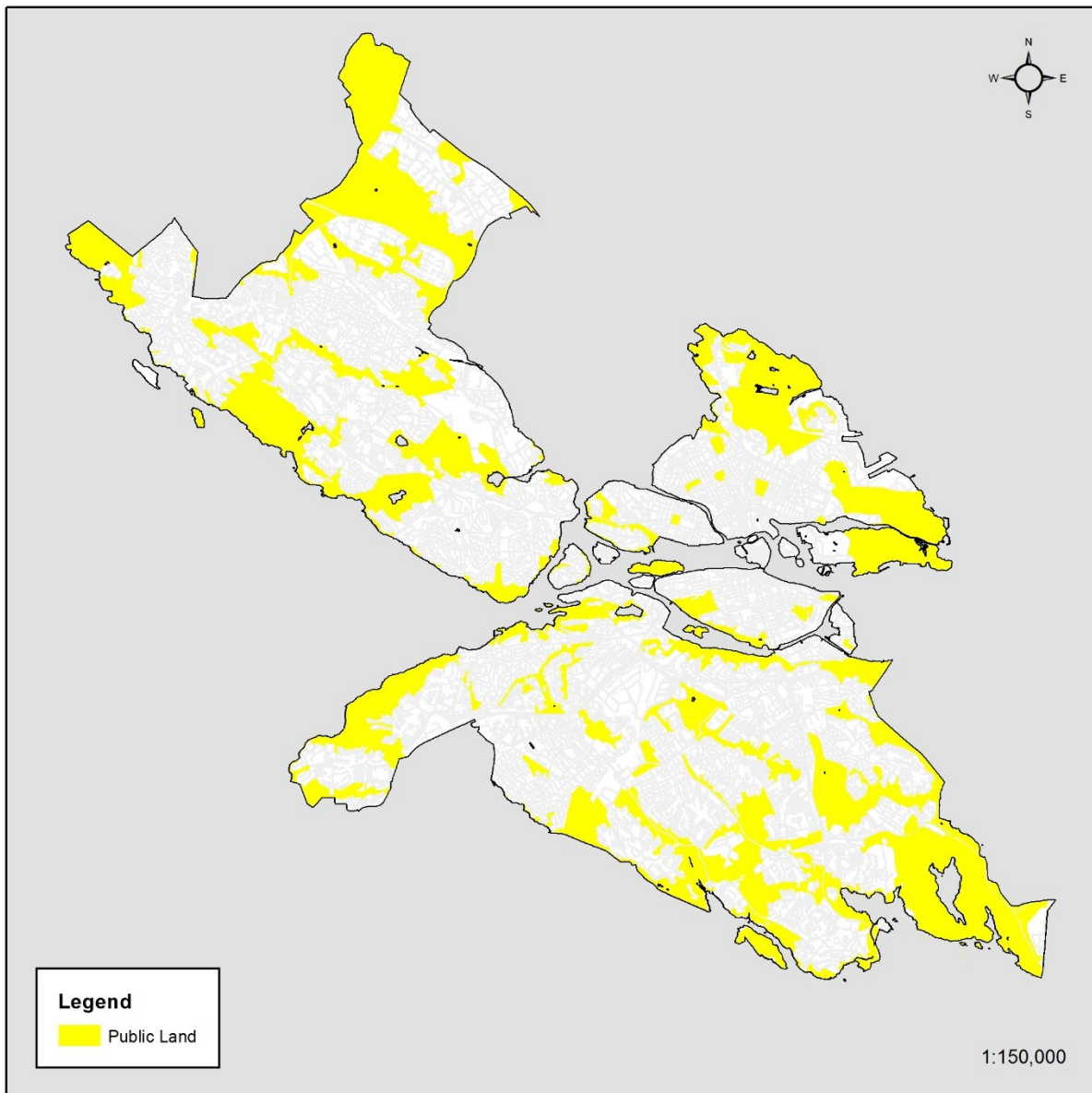


Figure 9. Public land in Stockholm

2. The *Public Land* feature class was intersected with the *PGS* (Figure 8), which enabled the calculation of *PGS* on all *Public Land* parcels.

#### 3.4.2.4 Stockholm - Accessibility to PGS

The Stockholm case study follows the same methodology as described in the Christchurch case study (see section 3.4.1.4).

### 3.4.2.5 Stockholm - Accessibility to Food Retailers

The Stockholm case study follows the same methodology used for the Christchurch case study as described in section 3.4.1.5, except that the *Food Retailers* data included only supermarkets and greengrocers (Figure 10).

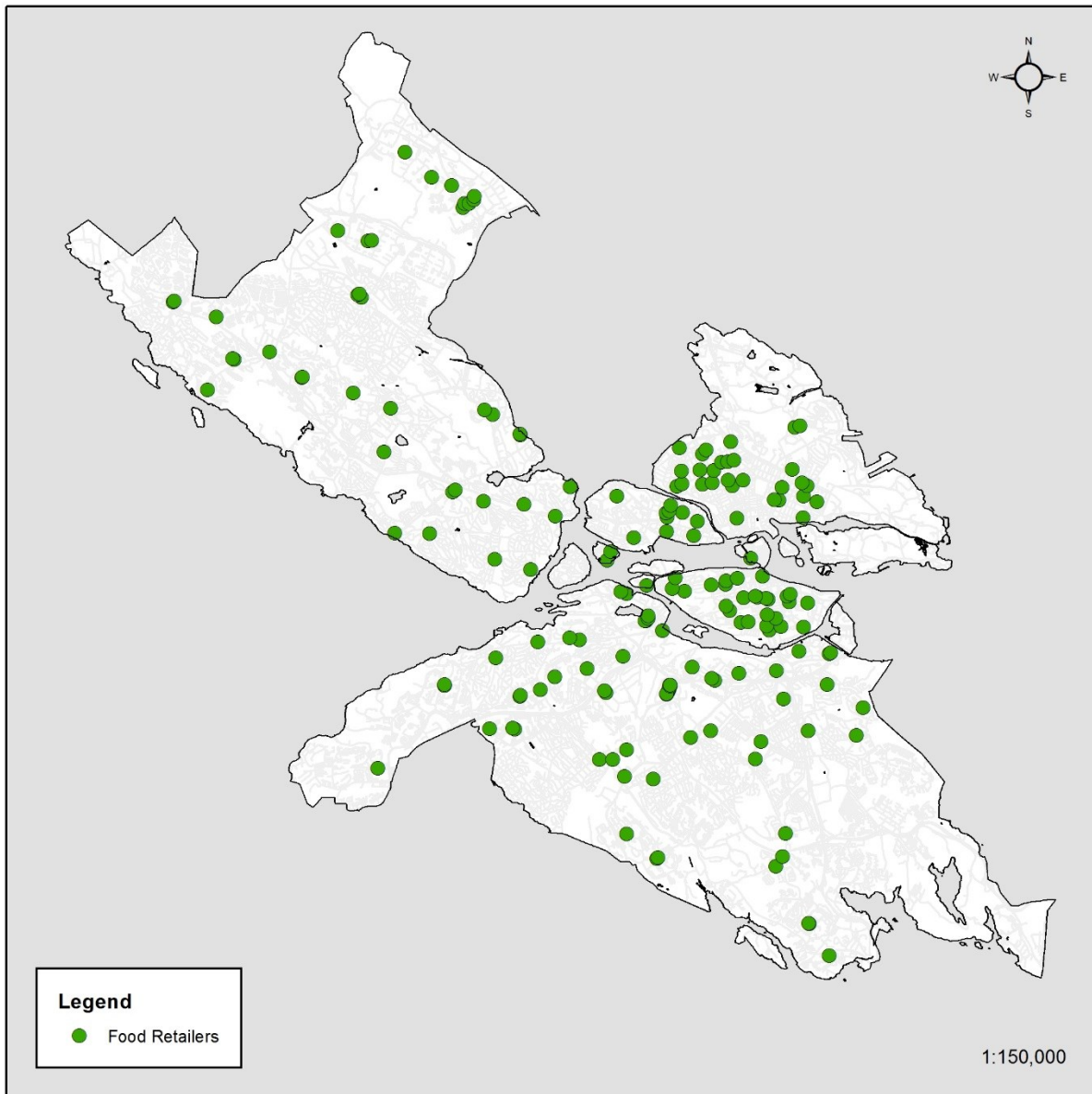


Figure 10. Food retailer locations in Stockholm

#### **3.4.2.6 Stockholm - Household Accessibility categories**

As with the Christchurch case study, once the network analyses were complete, the household resilience classes were calculated by combining the *Access to PGS* and *Access to Food Retailer* categories, as described in section 3.3.3.

## 4 RESULTS

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The chapter is divided into two sections, and presents the results from the two case studies, Christchurch and Stockholm. A collection of maps has been produced for each case study to show how the different variables for *PGS required*, and *Maximum travel distance* affect the results. For each case study, the following maps are provided:

- Access to PGS
  - Household access to 70m<sup>2</sup> PGS within 1km
  - Household access to 70m<sup>2</sup> PGS within 5km
  - Household access to 372m<sup>2</sup> PGS within 1km
  - Household access to 372m<sup>2</sup> PGS within 5km
  - Household access to 650m<sup>2</sup> PGS within 1km
  - Household access to 650m<sup>2</sup> PGS within 5km
- Access to food retailer
  - Household access to food retailer within 1km
  - Household access to food retailer within 5km
- Resilience category
  - Household resilience category for 70m<sup>2</sup> PGS requirement within 1km scenario
  - Household resilience category for 70m<sup>2</sup> PGS requirement within 5km scenario
  - Household resilience category for 372m<sup>2</sup> PGS requirement within 1km scenario
  - Household resilience category for 372m<sup>2</sup> PGS requirement within 5km scenario
  - Household resilience category for 650m<sup>2</sup> PGS requirement within 1km scenario
  - Household resilience category for 650m<sup>2</sup> PGS requirement within 5km scenario

The maps will be accompanied by summary tables showing:

- The count of households in each category
- The total *External PGS required* and *Public Land PGS available*

## 4.1 CHRISTCHURCH CASE STUDY

### 4.1.1 Access to PGS - Christchurch

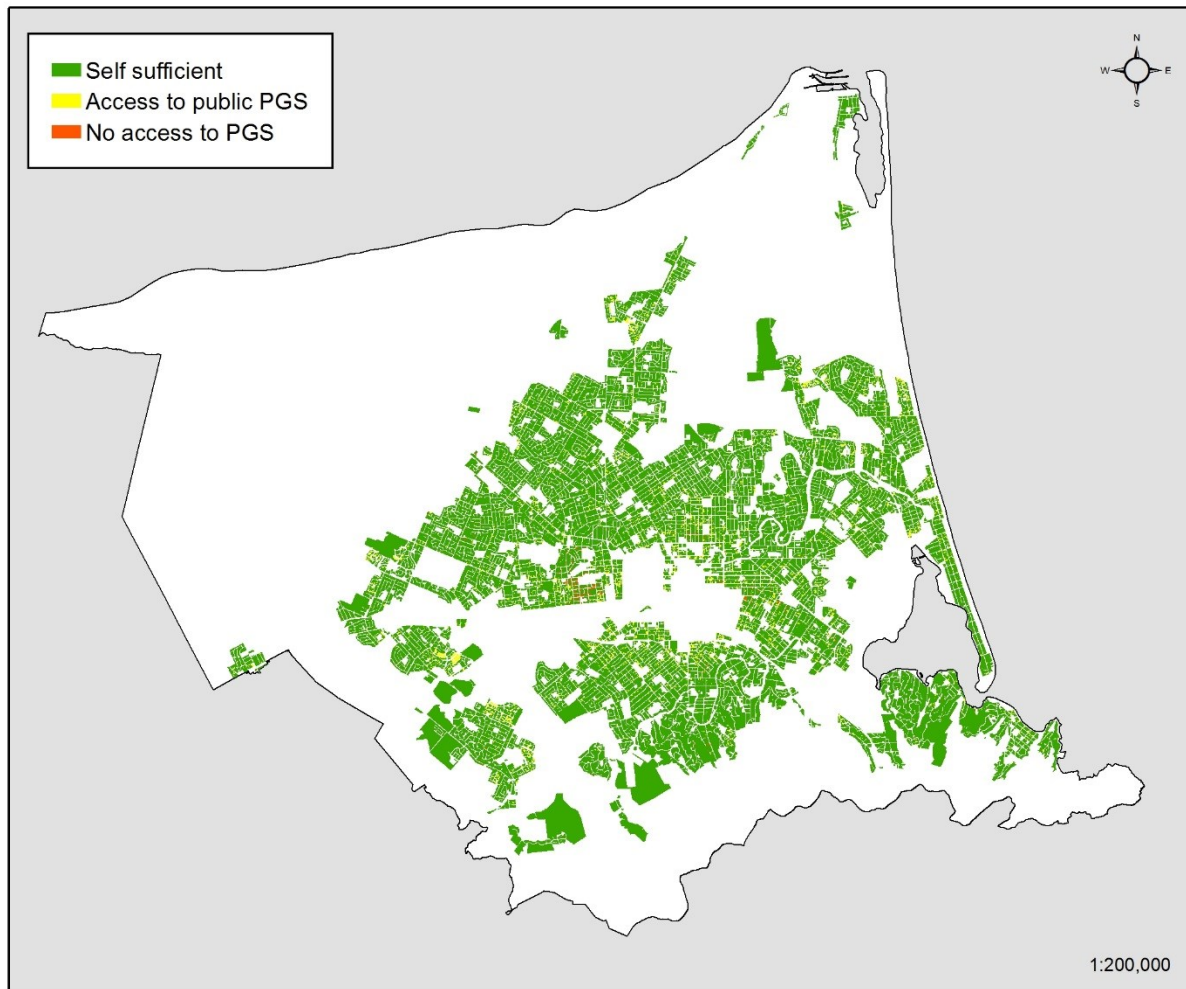
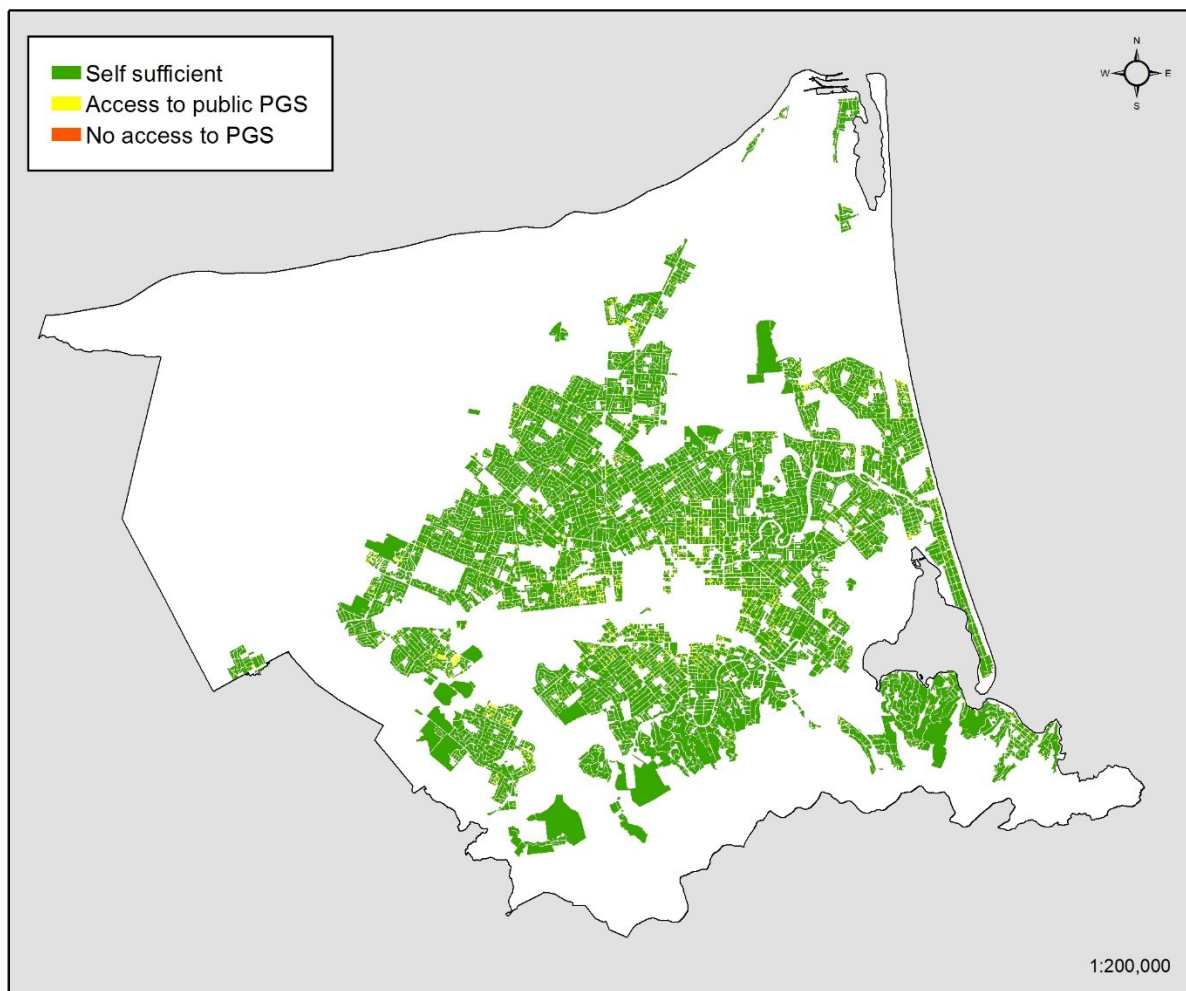


Figure 11. Household access to 70m<sup>2</sup> PGS within 1km in Christchurch

Over 91% of Christchurch households fall in the *self sufficient* category when using the 70m<sup>2</sup> PGS requirement scenario. With a maximum travel distance of 1km, 8% of households have *no access to PGS* (Figure 11), this drops to only 0.006% (8 households) when the travel distance is increased to 5km (Figure 12).



*Figure 12. Household access to 70m<sup>2</sup> PGS within 5km in Christchurch*

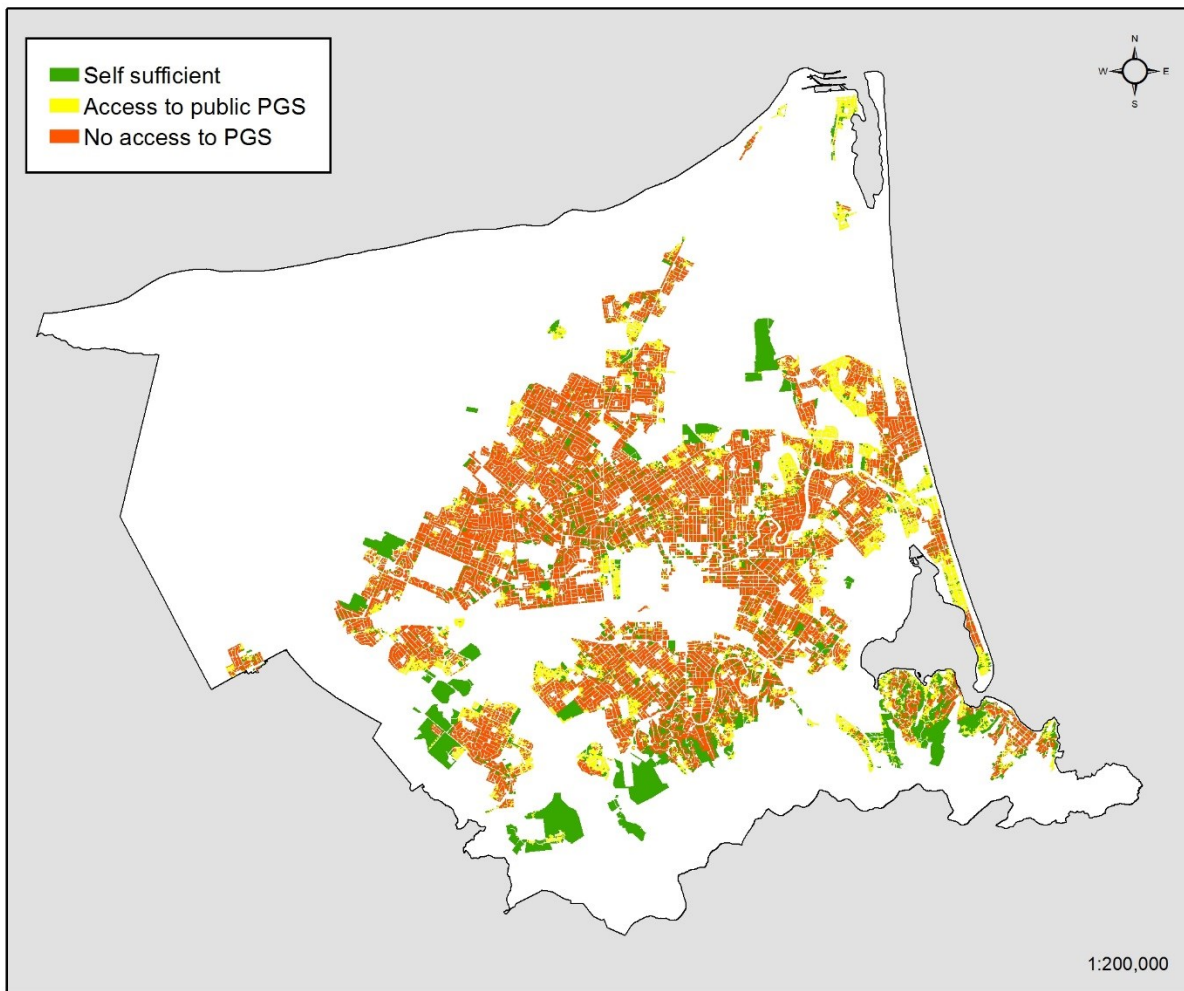
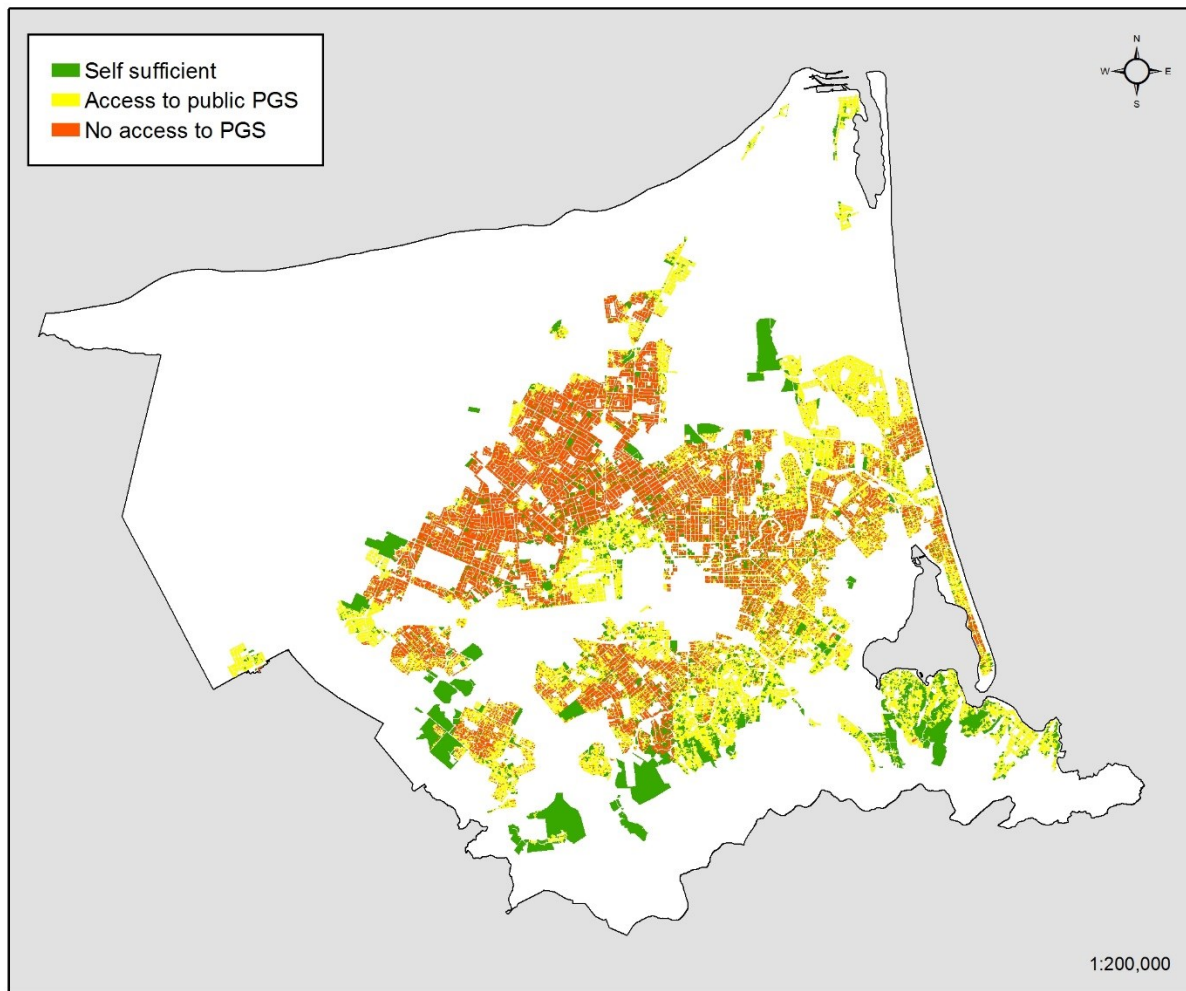


Figure 13. Household access to 372m<sup>2</sup> PGS within 1km in Christchurch

By increasing the PGS requirement to 372m<sup>2</sup>, the percentage of *self sufficient* households drops to 6.5%, and over 74% of households are unable to fulfill their PGS requirement within 1km (Figure 13). When the maximum travel distance is increased to 5km, 46% of households have *access to public PGS*, lowering the percentage of households with *no access to PGS* to 48% (Figure 14).





*Figure 14. Household access to 372m<sup>2</sup> PGS within 5km in Christchurch*



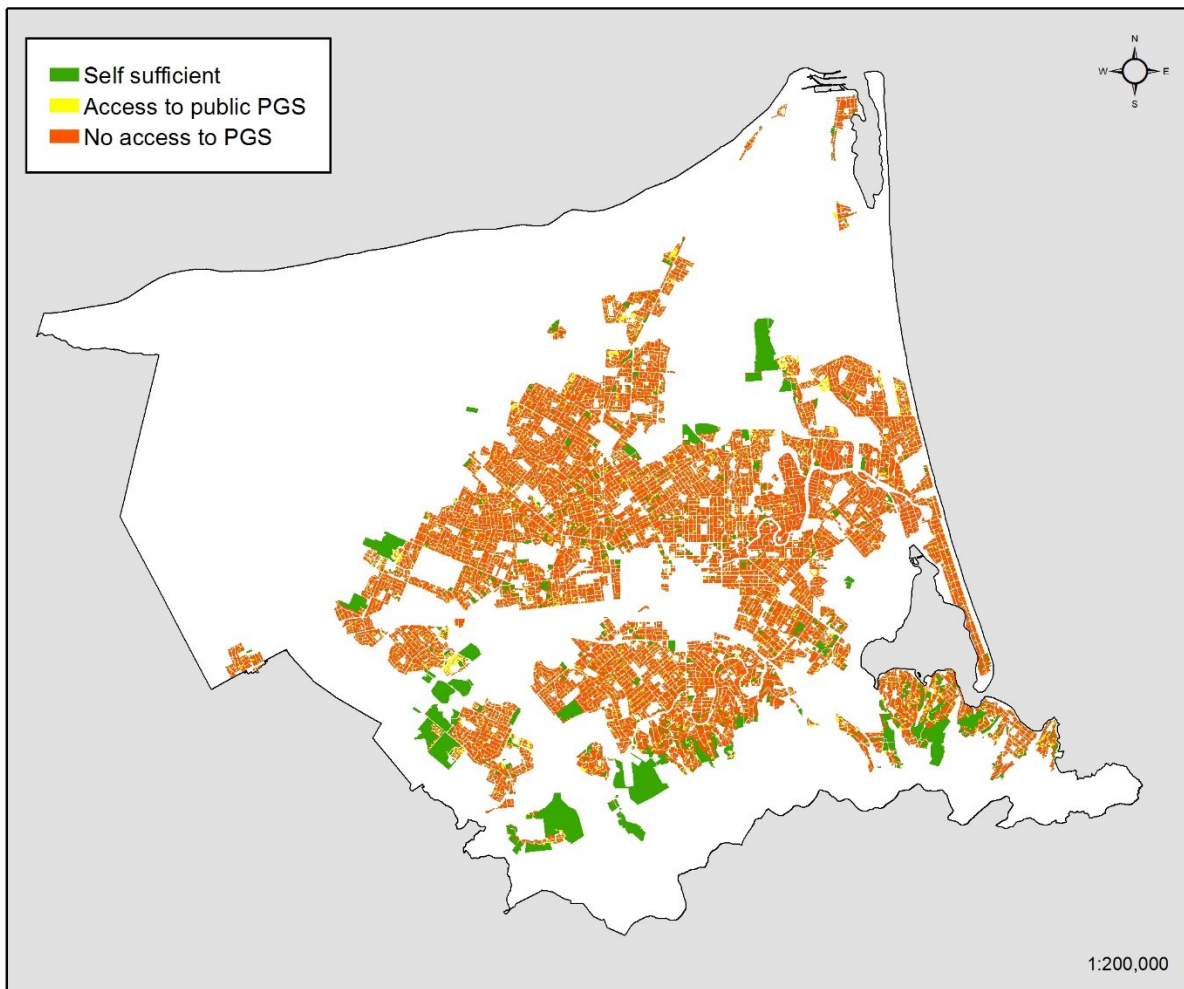
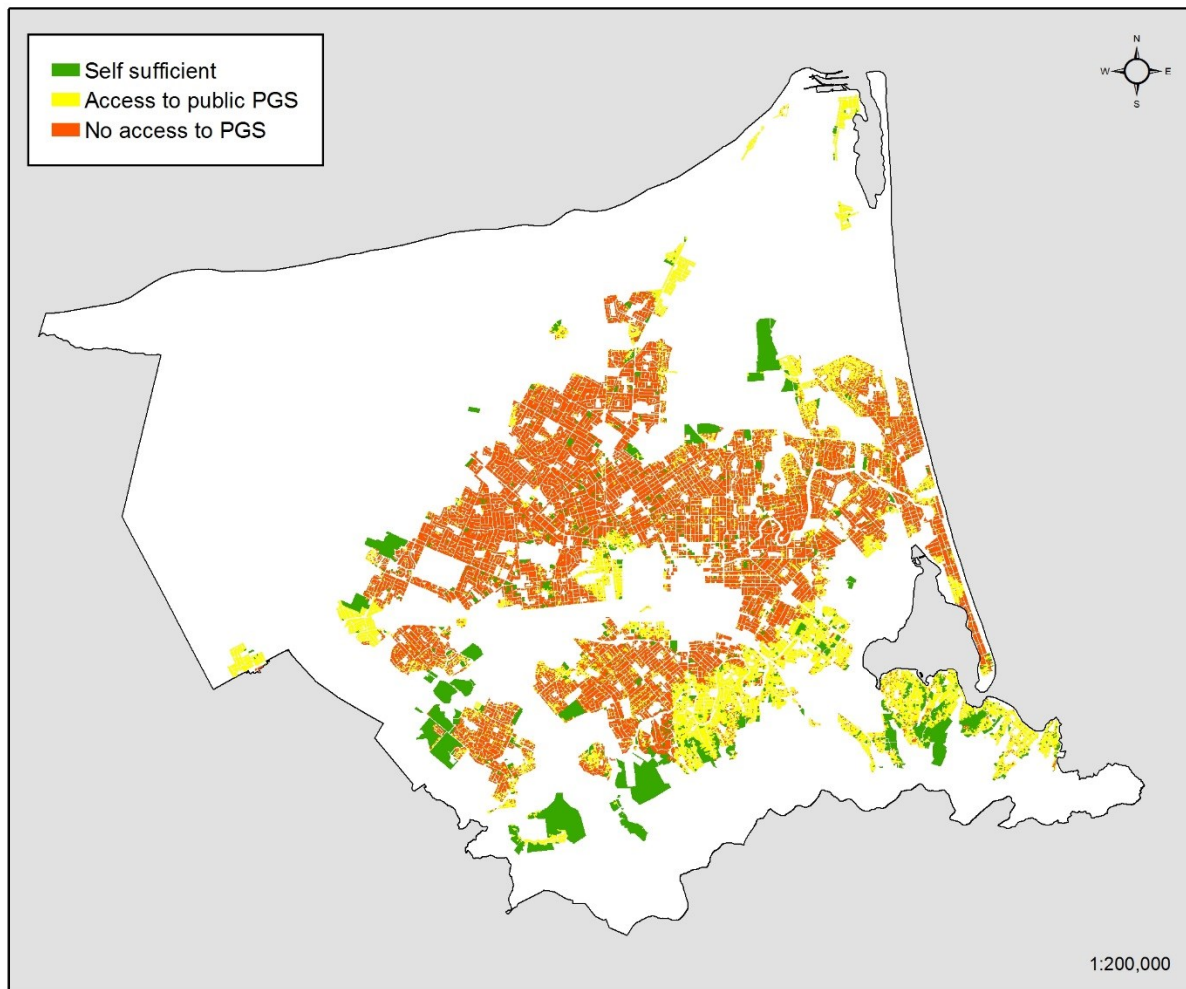


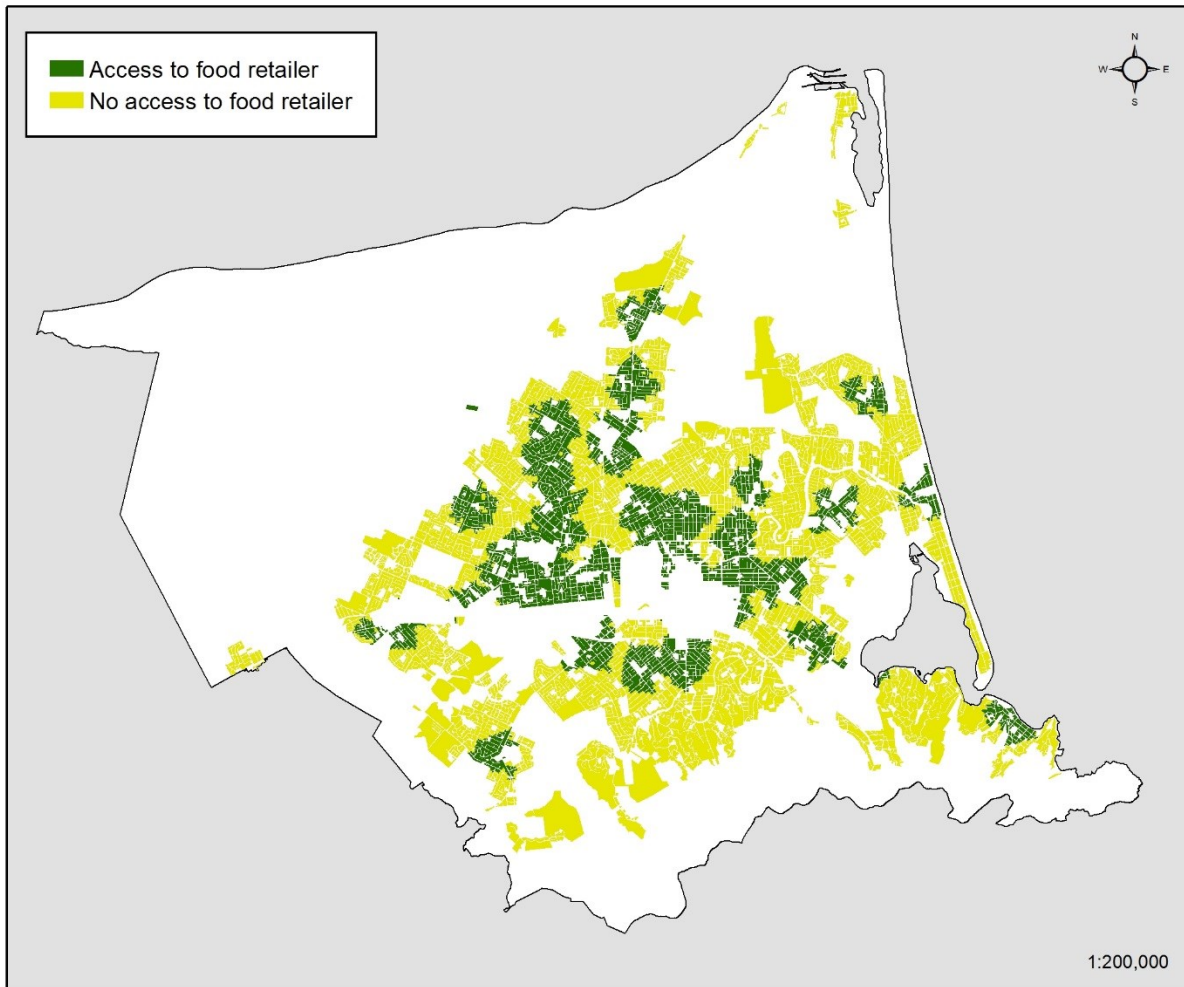
Figure 15. Household access to 650m<sup>2</sup> PGS within 1km in Christchurch

Households in the *self sufficient* category account for only 2% when the *PGS* requirement is raised to 650m<sup>2</sup> when using the maximum travel distance of 1km, and 87% of households have no access to the required *PGS* (Figure 15). When the maximum travel distance is increased to 5km, 28% of households gain access to public land *PGS*, leaving 69% without access to adequate *PGS* (Figure 16).



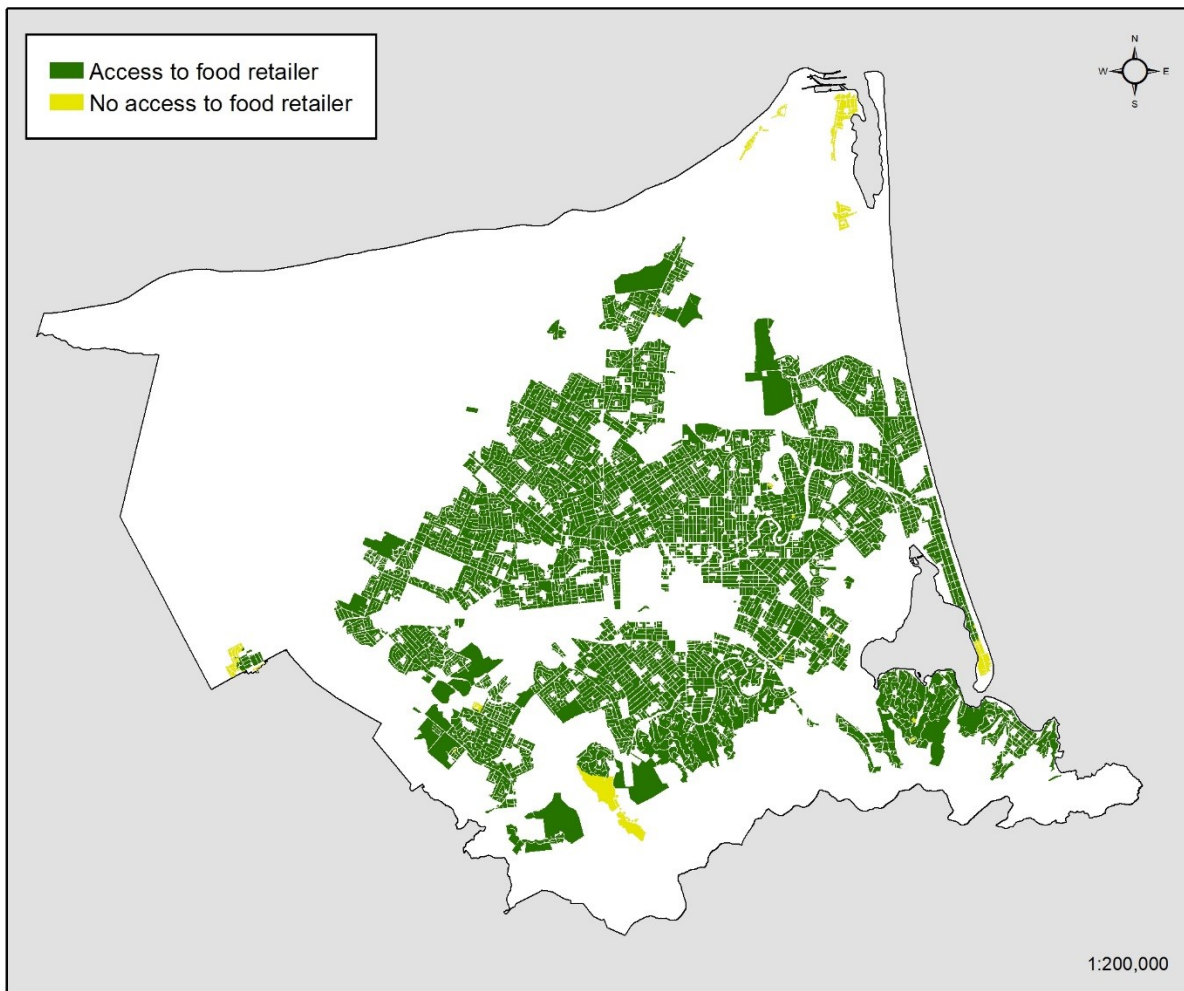
*Figure 16. Household access to 650m<sup>2</sup> PGS within 5km in Christchurch*

#### 4.1.2 Access to food retailer - Christchurch



*Figure 17. Household access to food retailer within 1km in Christchurch*

In Christchurch, only 37% of households have access to a food retailer within 1km (Figure 17), this value rises to over 98% when the maximum travel distance is raised to 5km (Figure 18).



*Figure 18. Household access to food retailer within 5km in Christchurch*

### 4.1.3 Resilience category - Christchurch

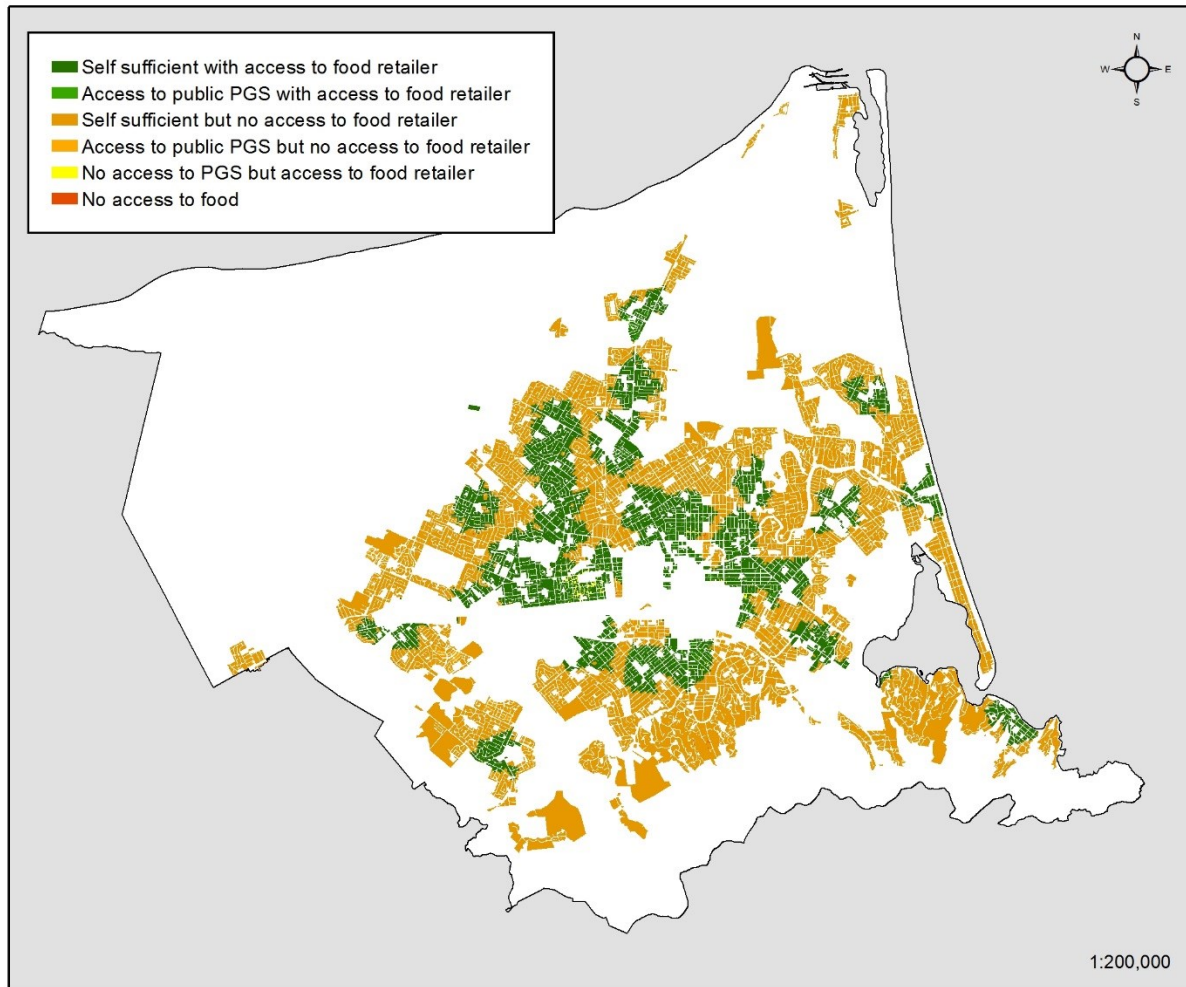


Figure 19. Household resilience category for 70m<sup>2</sup> PGS requirement within 1km scenario in Christchurch

Although there is a high number of *self sufficient* households in the 70m<sup>2</sup> PGS requirement scenario, when the maximum travel distance of 1km is used, only 32% of households fall into the *Self sufficient with access to food retailer* category, and 59% fall within the *Self sufficient but no access to food retailer* category (Figure 19). By increasing the maximum travel distance to 5km, over 90% of households fall into the *Self sufficient with access to food retailer* category (Figure 20).



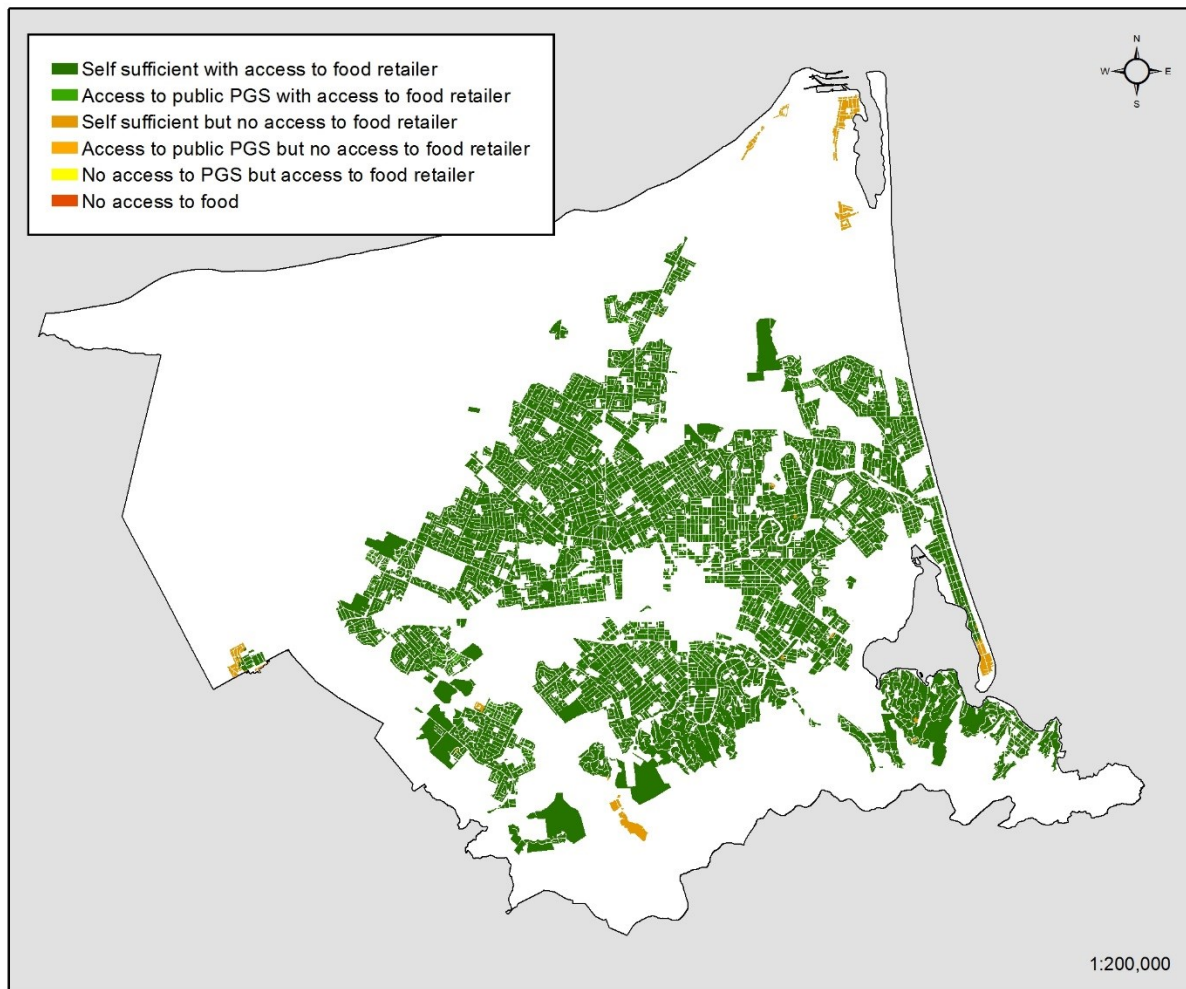


Figure 20. Household resilience category for 70m<sup>2</sup> PGS requirement within 5km scenario in Christchurch

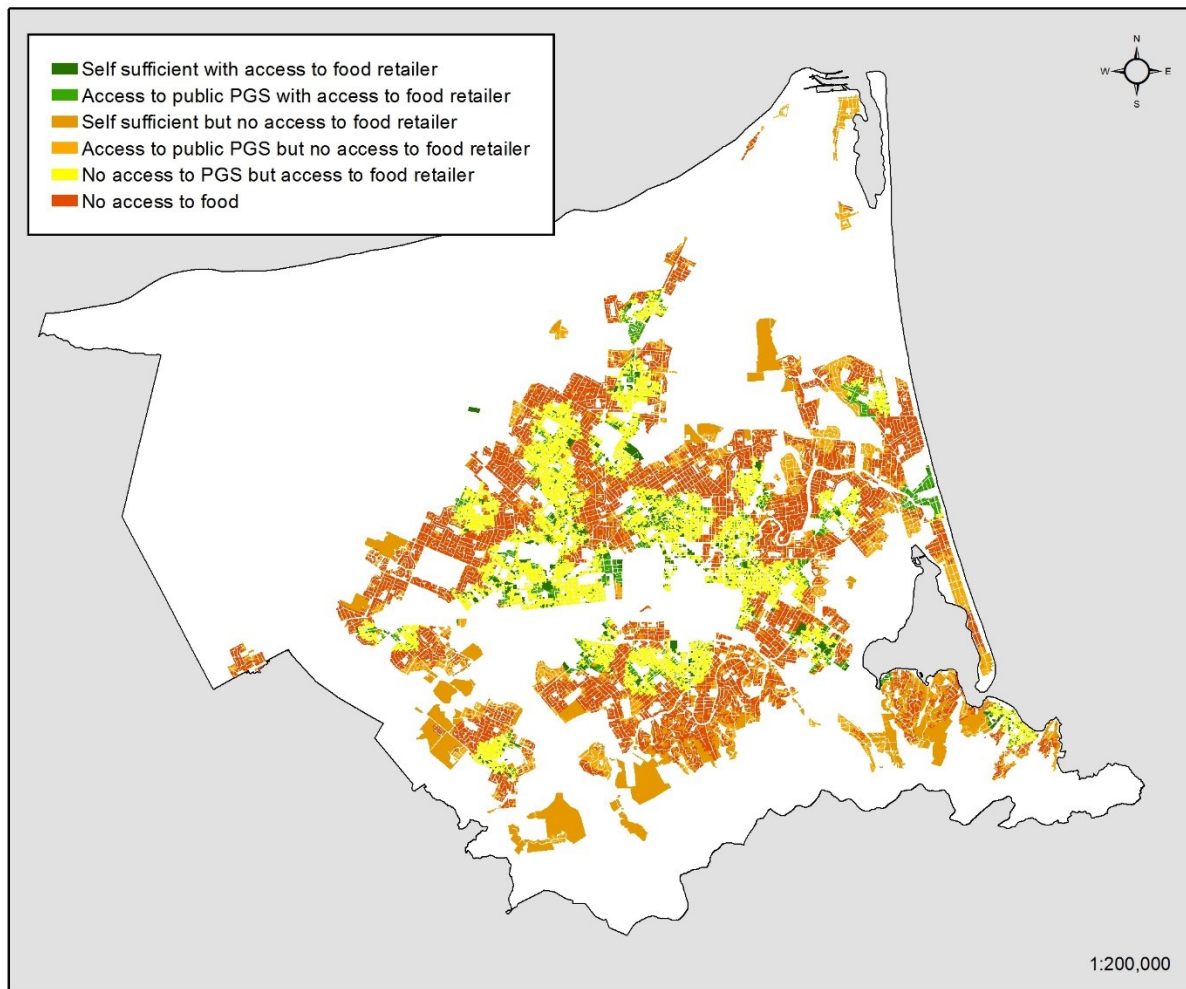


Figure 21. Household resilience category for 372m<sup>2</sup> PGS requirement within 1km scenario in Christchurch

When using the 372m<sup>2</sup> PGS requirement scenario with a maximum travel distance of 1km (Figure 21), 2.5% of households are categorised as *Self sufficient with access to food retailer*, and a further 5% have *access to public PGS with access to a food retailer*. 45% of households have *no access to food*. When the maximum travel distance is increased to 5km (Figure 22), 6% of households are categorised as *Self sufficient with access to food retailer*, and 45% have *access to public PGS with access to food retailer*. The number of households with *no access to food* drops to less than 0.2% (227 households) when the maximum travel distance is 5km.

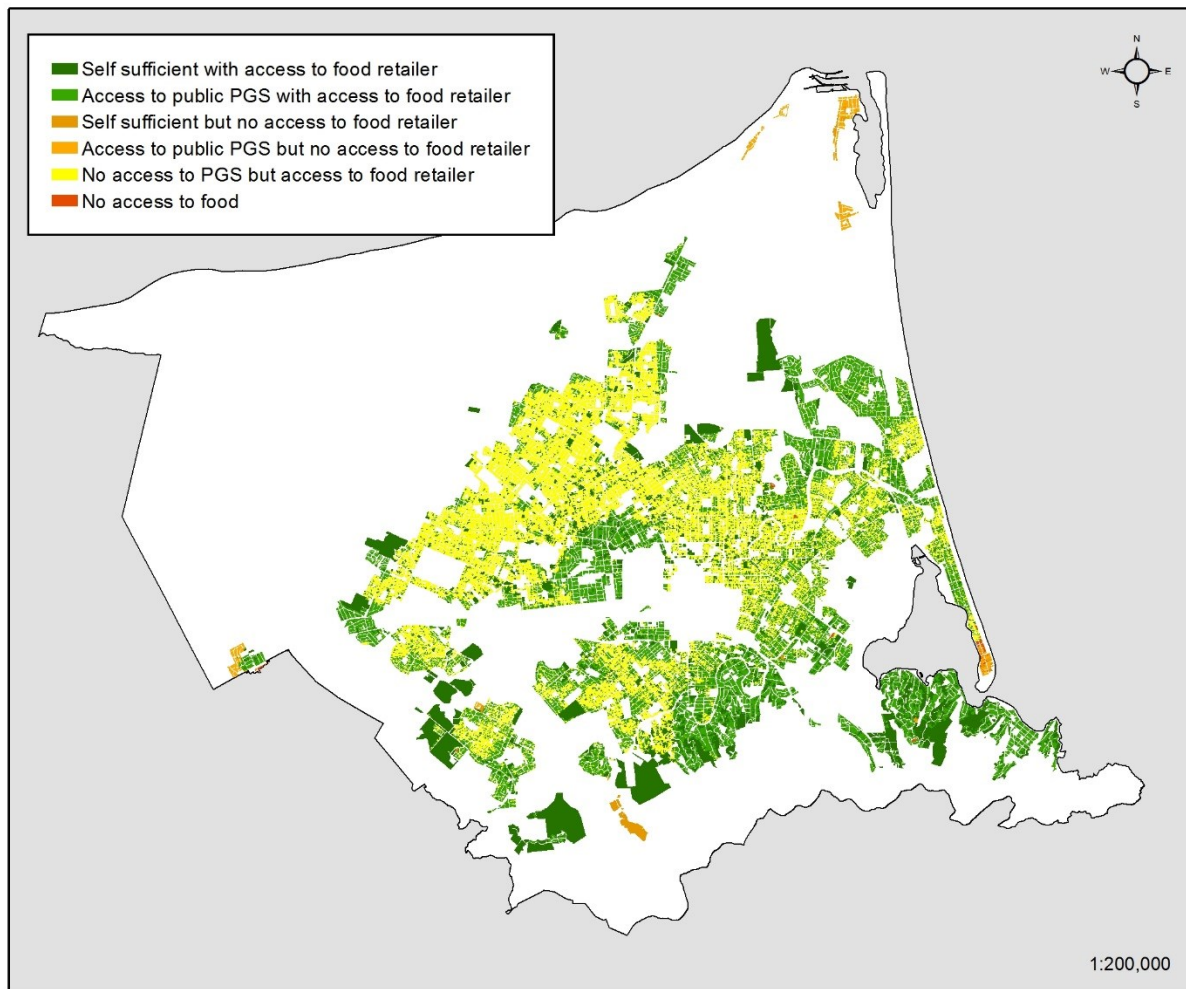


Figure 22. Household resilience category for 372m<sup>2</sup> PGS requirement within 5km scenario in Christchurch



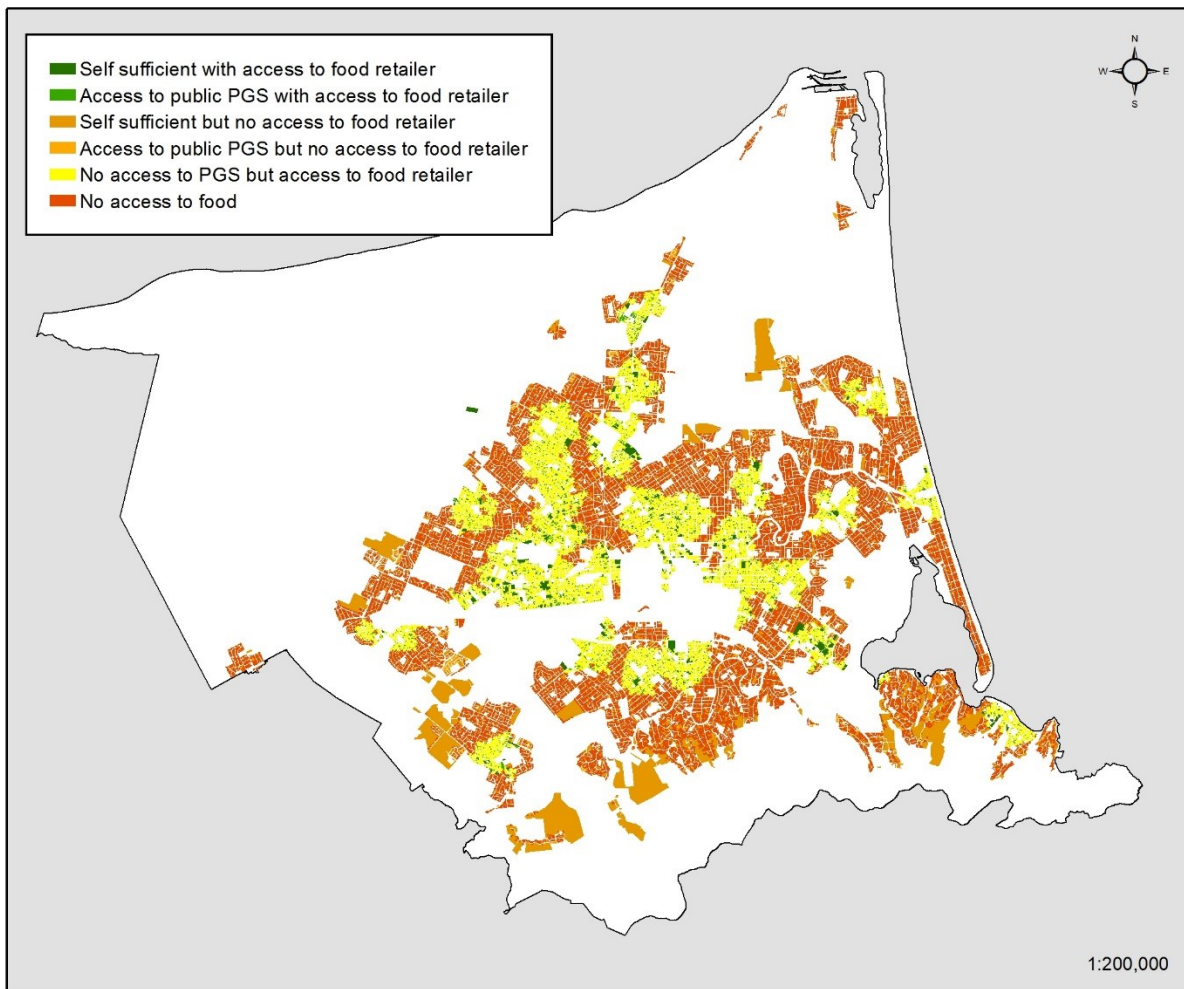
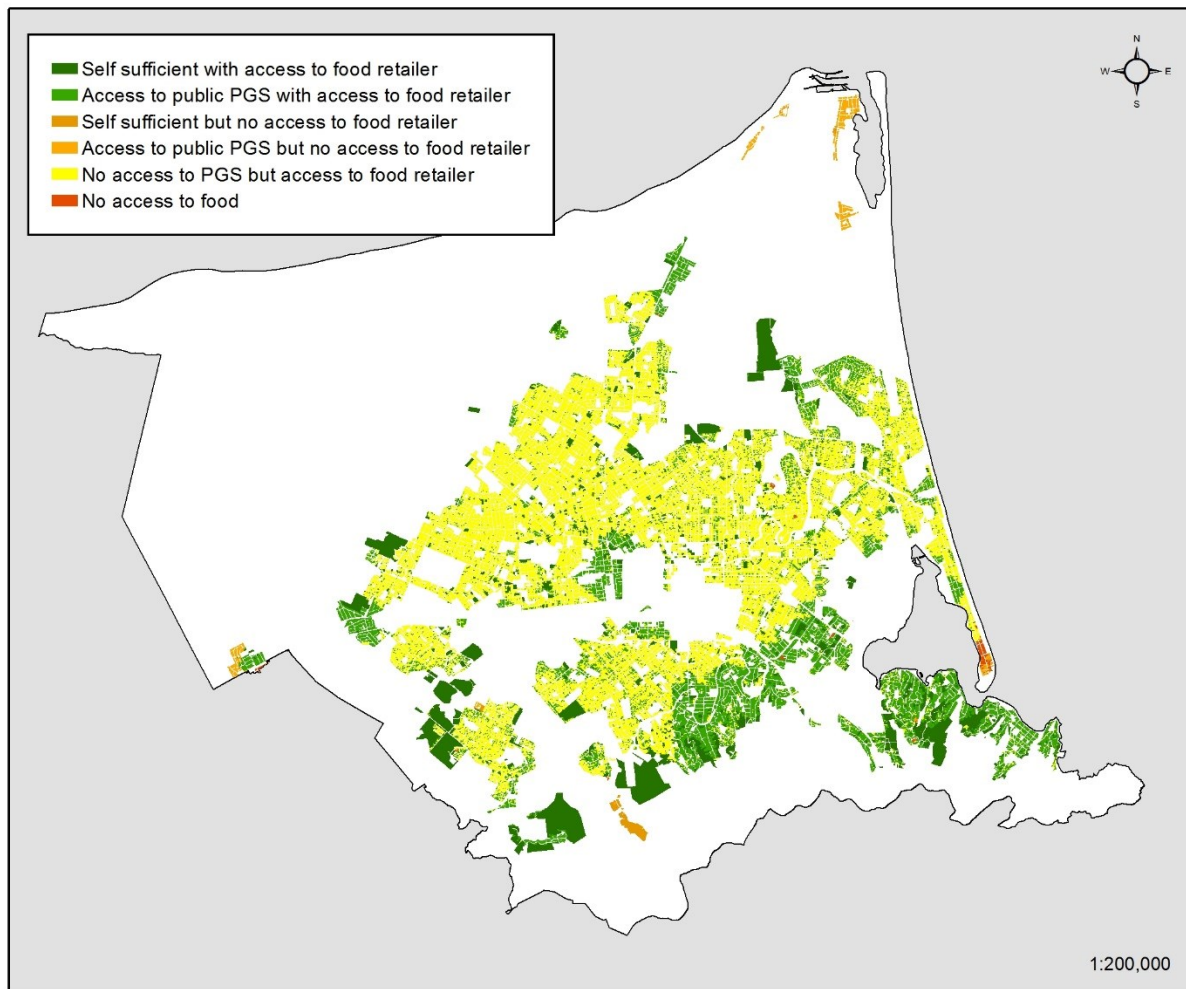


Figure 23. Household resilience category for 650m<sup>2</sup> PGS requirement within 1km scenario in Christchurch

Using the 650m<sup>2</sup> PGS requirement scenario within a 1km maximum travel distance (Figure 23), less than 1% of households fall into the *Self sufficient with access to food retailer* category, and 4% have *access to public PGS with access to a food retailer*. 33% have *no access to PGS but access to food retailer*, and 54% have *no access to food*. In the 650m<sup>2</sup> PGS requirement scenario with a maximum travel distance of 5km (Figure 24), 2% of households fall into the *self sufficient with access to food retailer* category, and 27% have *access to public PGS with access to a food retailer*. 69% have *no access to PGS but access to food retailer*, and 0.3% have *no access to food* (392 households).



*Figure 24 Household resilience category for 650m<sup>2</sup> PGS requirement within 5km scenario in Christchurch*

Table 9 below shows the the percentage of households that fall into each category for each scenario.

Christchurch	Households (percent of total)					
	1km			5km		
Access to food retailer						
Access to food retailer	36.9			98.7		
No access to food retailer	63.1			1.3		
Access to PGS	70m²	372m²	650m²	70m²	372m²	650m²
Self sufficient	91.6	6.5	2.1	91.6	6.5	2.1
Access to public PGS	7.7	19.3	10.9	8.4	45.9	28.4
No access to PGS	0.7	74.2	87.0	0.0	47.6	69.5
Resilience category						
Self-sufficient with access to food retailer	33.0	2.5	0.8	90.3	6.4	2.1
Access to public PGS with access to food retailer	3.8	5.4	3.8	8.4	44.9	27.5
Self-sufficient but no access to food retailer	58.6	4.0	1.3	1.2	0.1	0.0
Access to public PGS but no access to food retailer	3.9	13.8	7.1	0.0	1.0	1.0
No access to PGS but access to food retailer	0.5	29.4	32.7	0.0	47.5	69.2
No access to food	0.2	44.8	54.3	0.0	0.2	0.3

\* Total households in access to food retailer category = 140,217, total households in other categories = 137,044, the difference is due to some households not having population statistics and therefore not being included in per person calculations of PGS requirement.

Table 9. Percentage of households in each category for Christchurch<sup>1</sup>

Table 10 shows the PGS land requirements for each scenario prior to any location-based analysis.

Land required per person	70m <sup>2</sup>	372m <sup>2</sup>	650 m <sup>2</sup>
<b>Total External PGS Required</b>	66ha	6,932ha	16,221ha
<b>Total Public Land PGS available</b>	6,014ha	6,014ha	6,014ha
<b>Difference</b>	+5948ha	-918ha	-10,207ha

Table 10. PGS statistics for Christchurch

<sup>1</sup> For table of count of households see appendix 8.2.1

## 4.2 STOCKHOLM CASE STUDY

### 4.2.1 Access to PGS - Stockholm

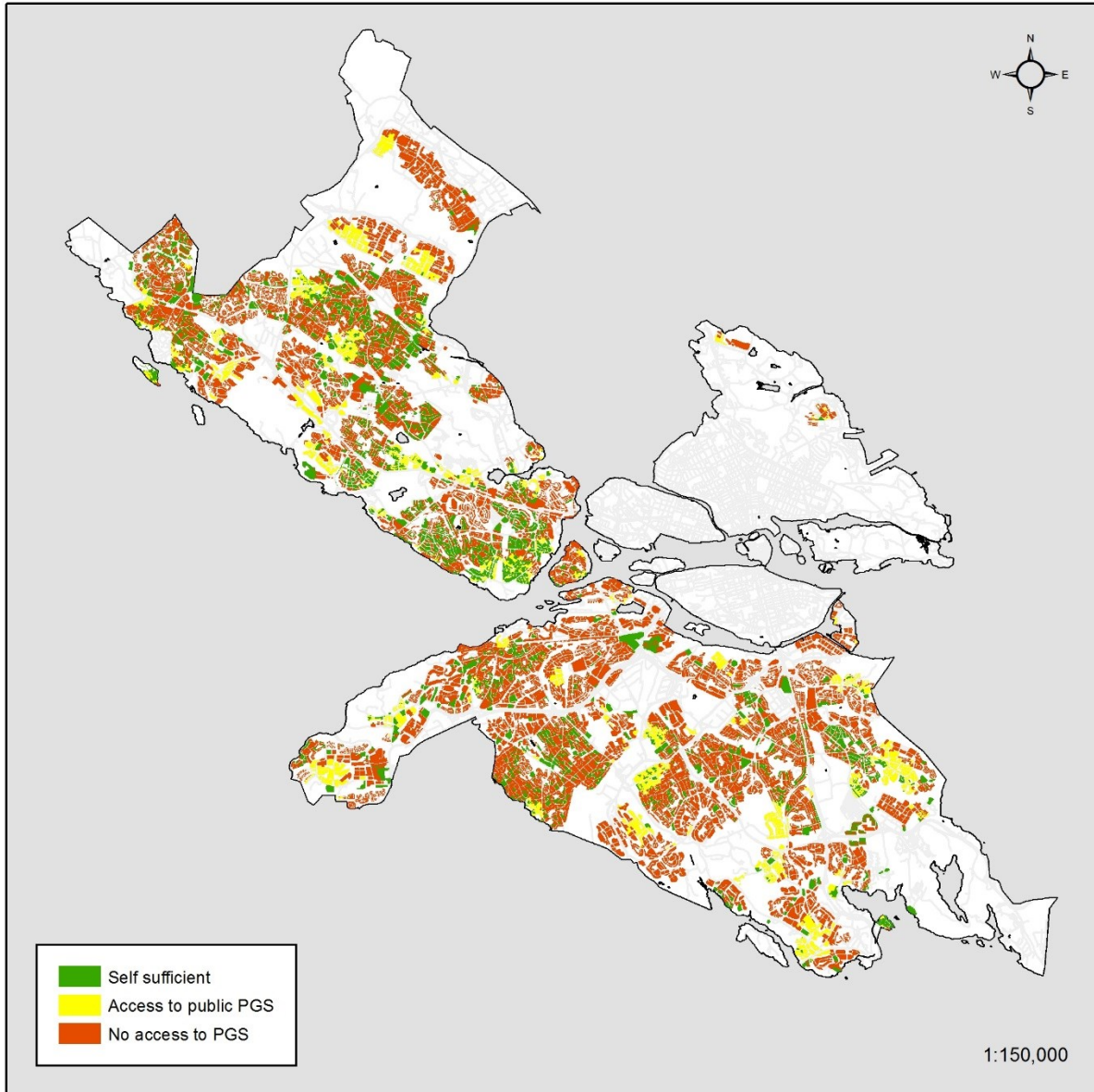


Figure 25. Household access to 70m<sup>2</sup> PGS within 1km in Stockholm

In Stockholm, 16% of households are *self sufficient* when using the 70m<sup>2</sup> PGS requirement scenario, a further 11% have access to PGS on public land within 1km (Figure 25), or 43% within 5km (Figure 26).

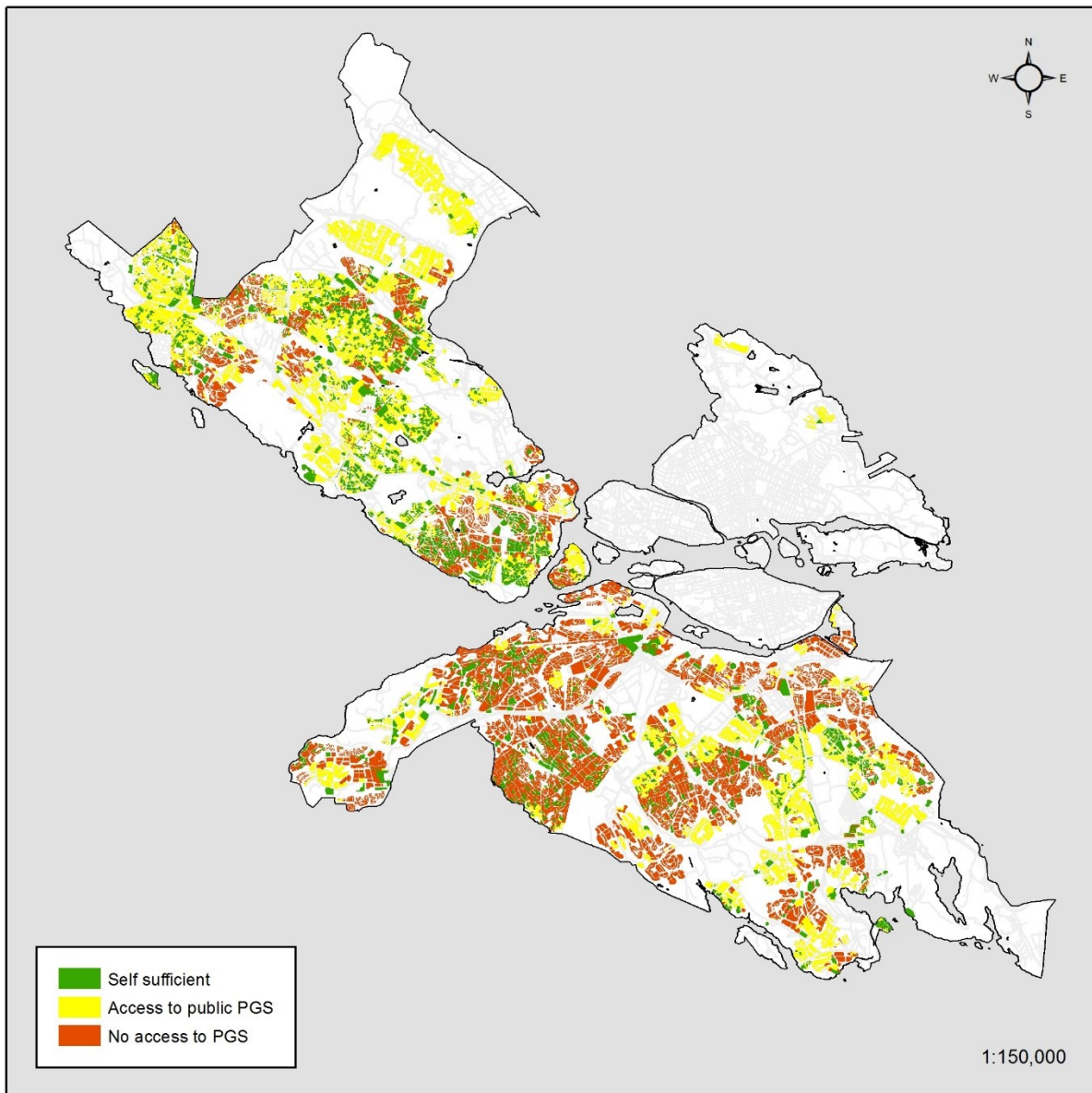


Figure 26. Household access to 70m<sup>2</sup> PGS within 5km in Stockholm



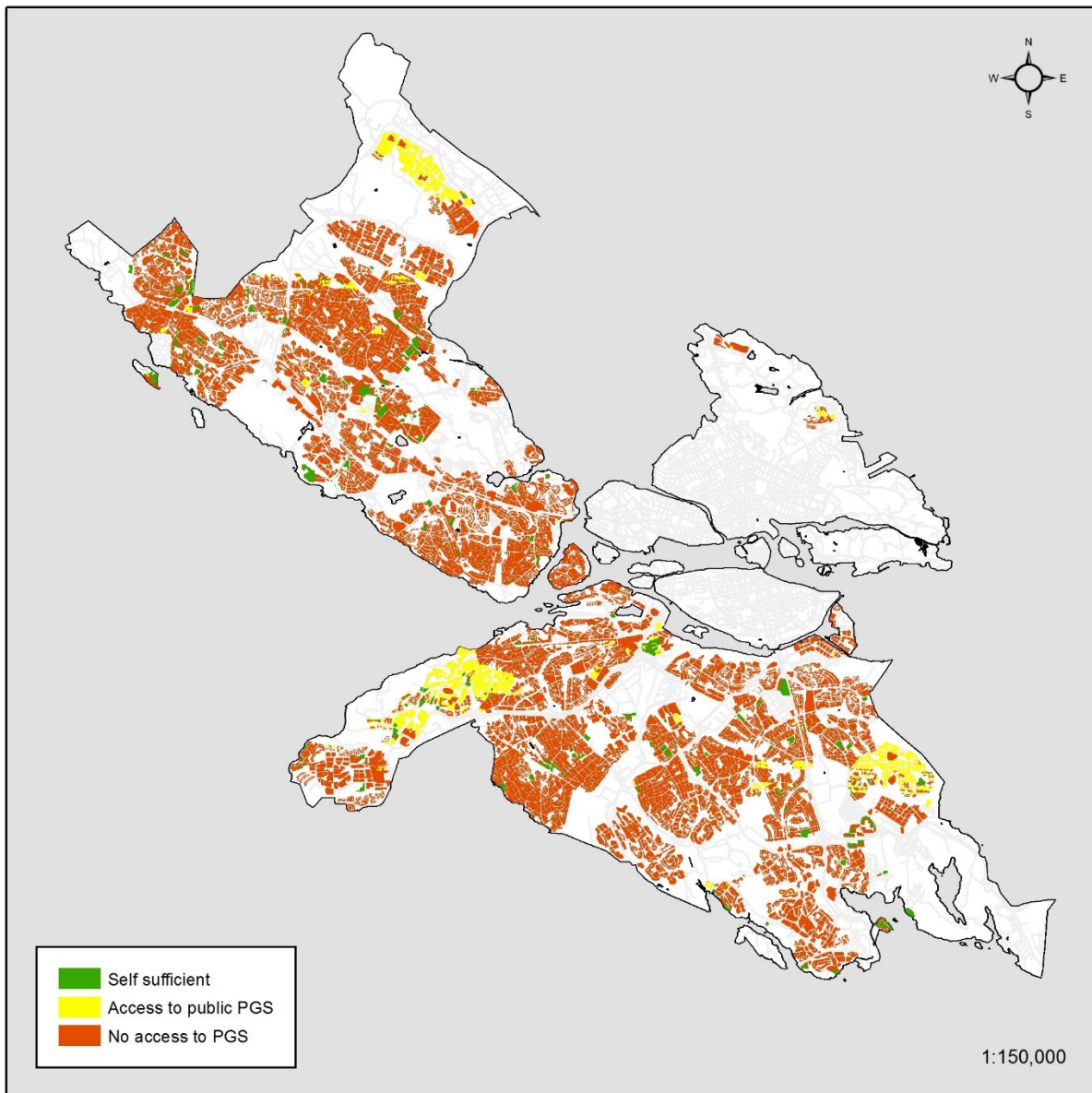


Figure 27. Household access to 372m<sup>2</sup> PGS within 1km in Stockholm

When the PGS requirement is increased to 372m<sup>2</sup>, only 0.7% of households fall into the *self sufficient* category. 93% of households do not have access to 372m<sup>2</sup> PGS within 1km (Figure 27), and 88% do not have access within 5km (Figure 28).

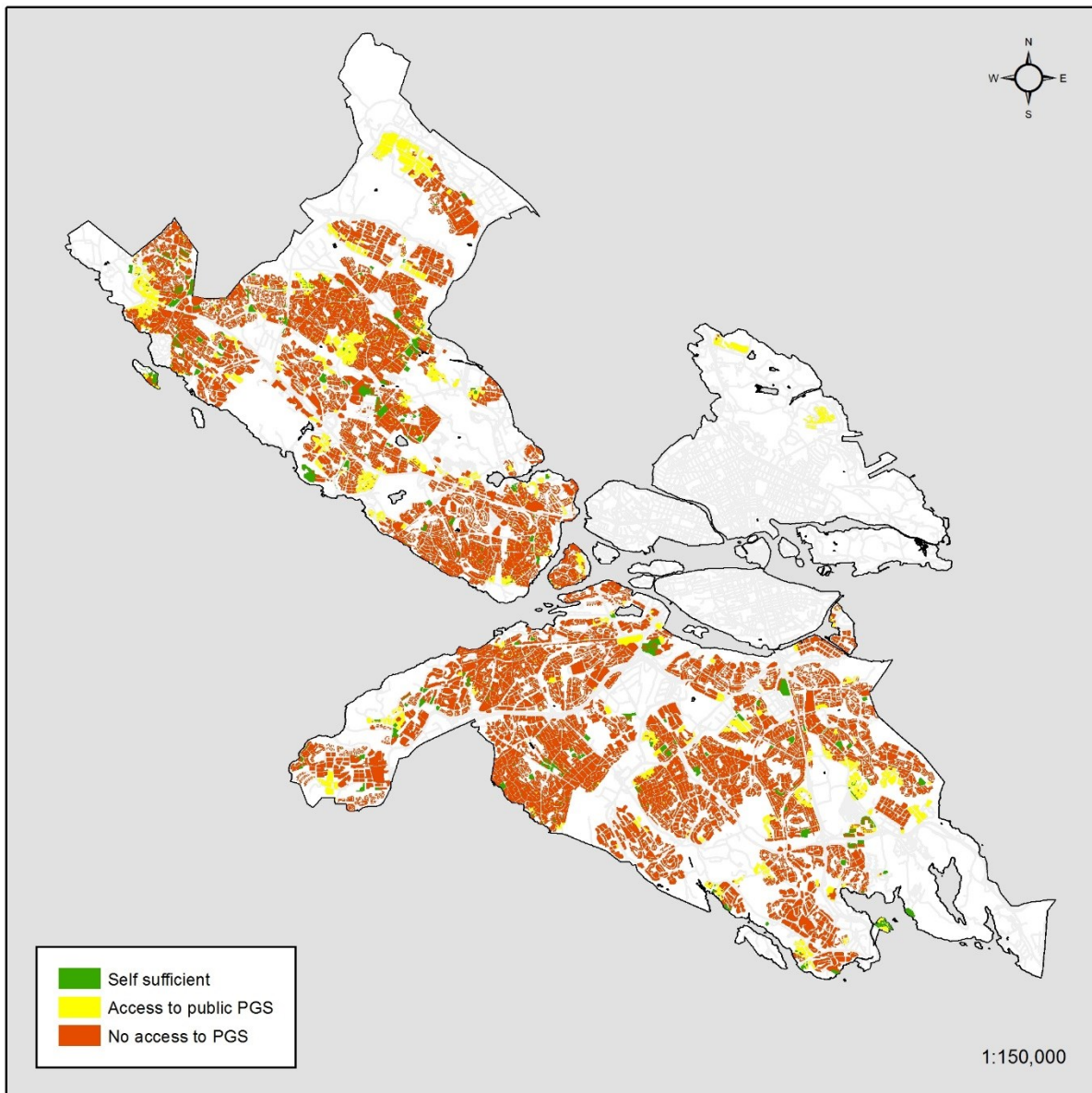


Figure 28. Household access to 372m<sup>2</sup> PGS within 5km in Stockholm

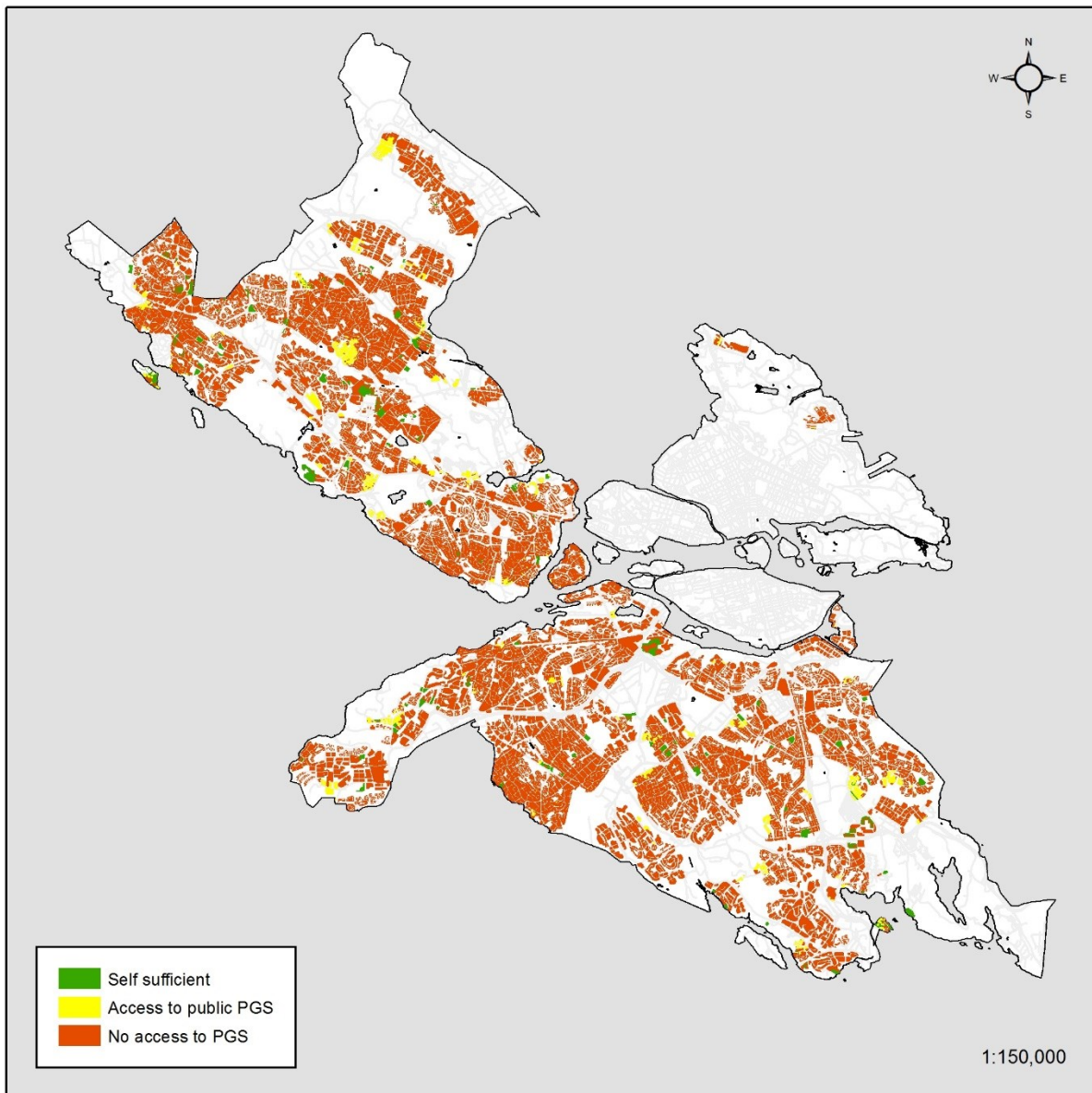


Figure 29. Household access to 650m<sup>2</sup> PGS within 1km in Stockholm

Less than 0.4% of households are *self sufficient* when using the 650m<sup>2</sup> PGS requirement scenario. Over 95% of households do not have access to the required PGS within 1km (Figure 29), and 93% still have no access to the required PGS when the maximum travel distance is increased to 5km (Figure 30).



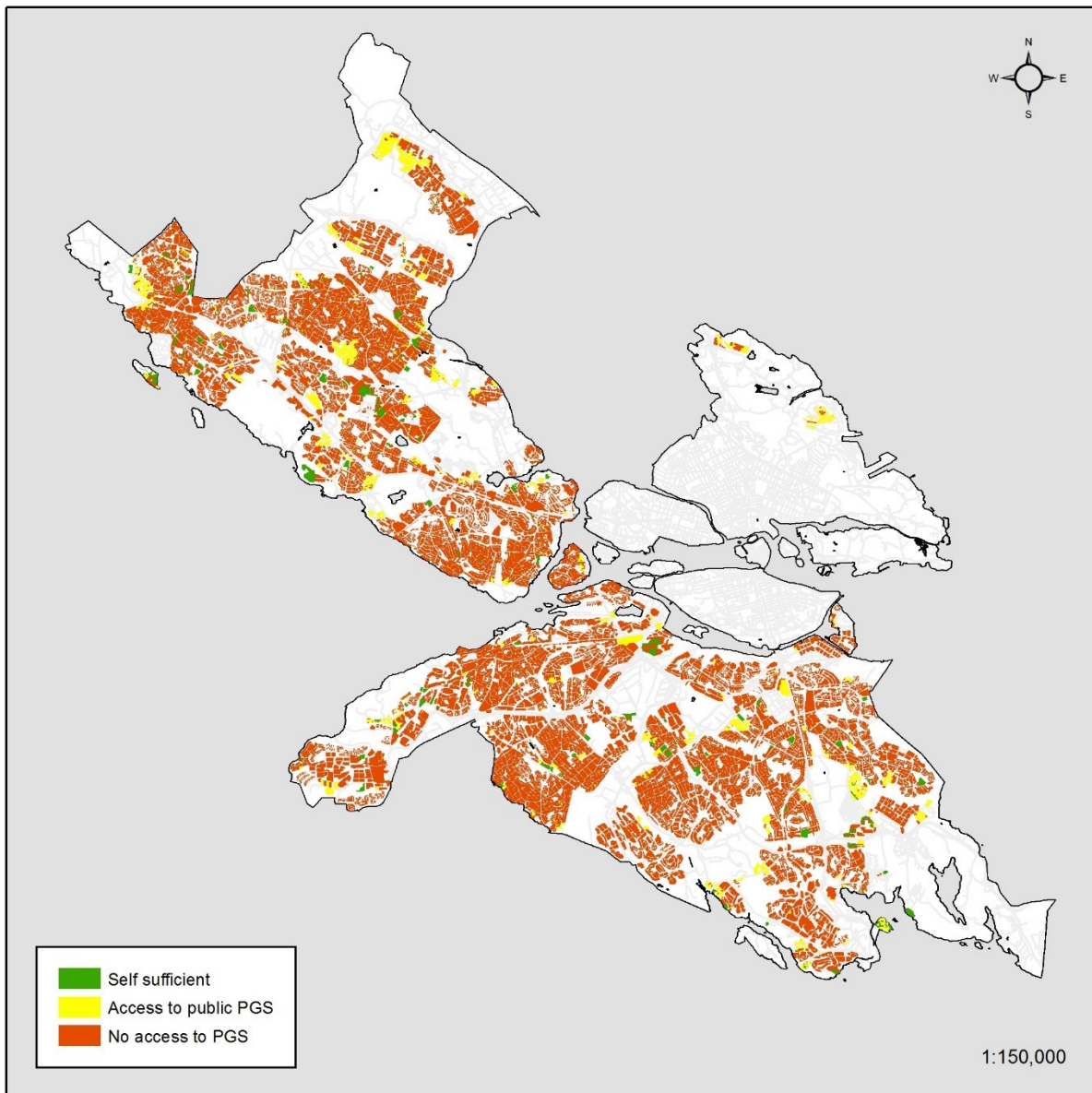
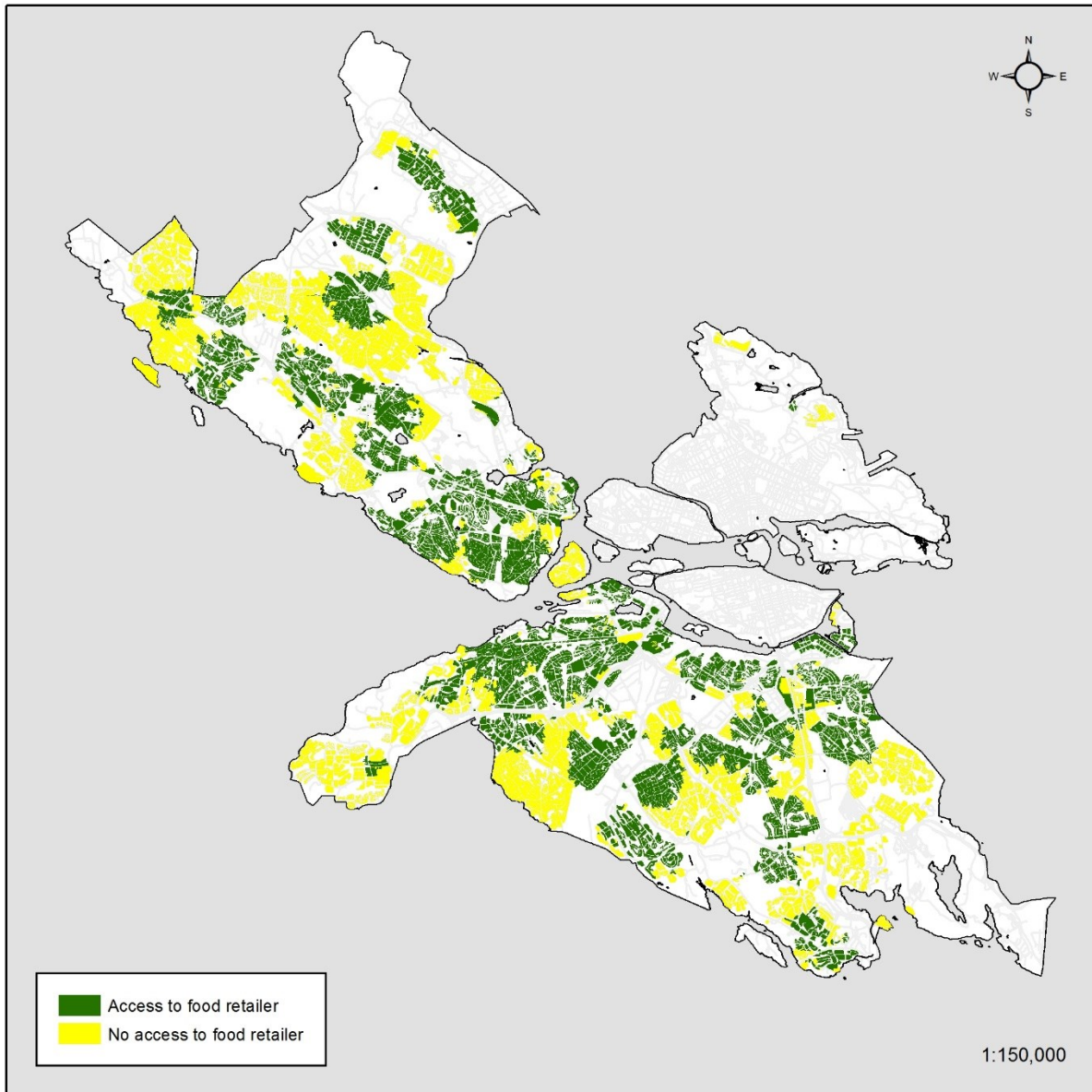


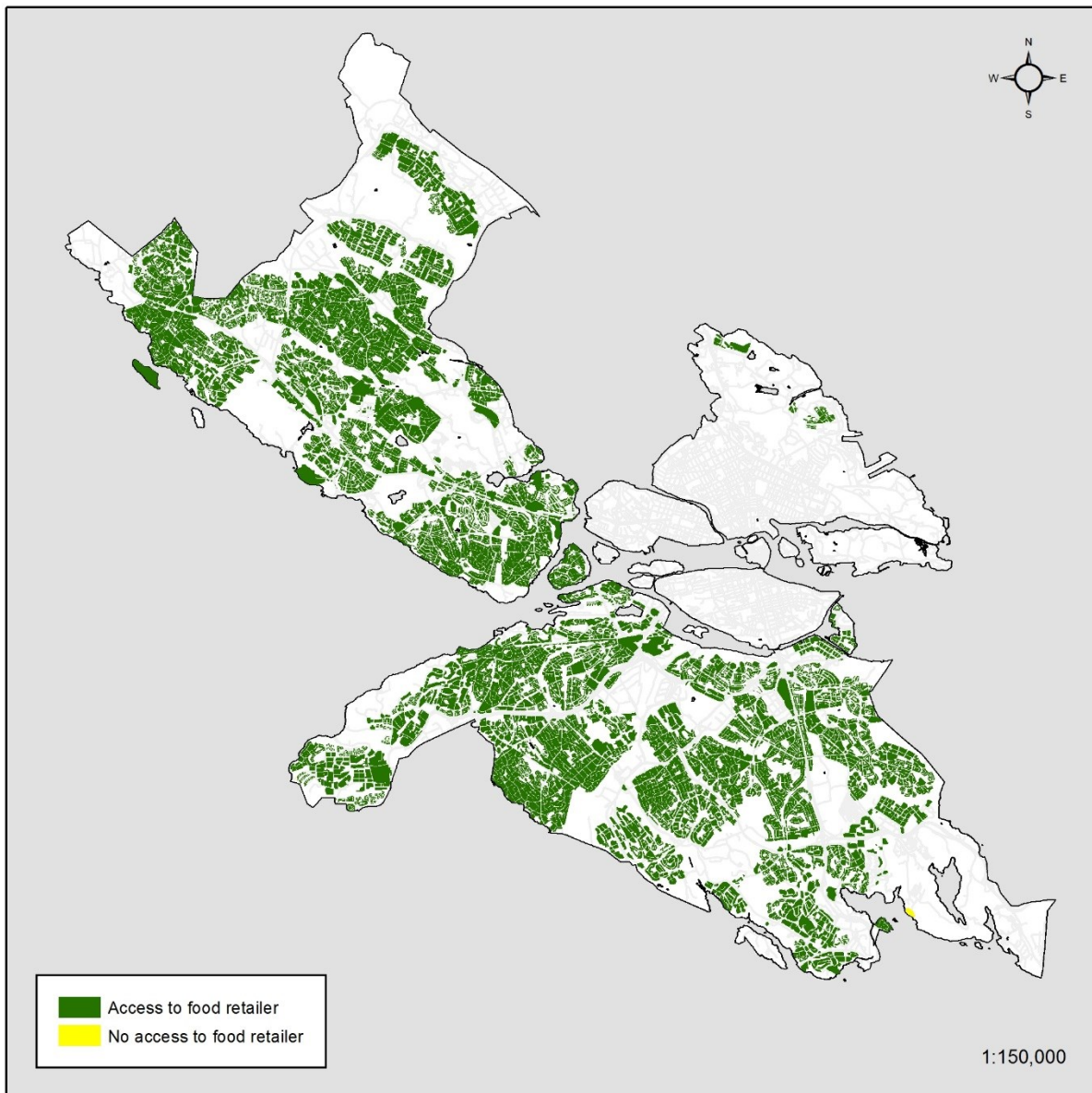
Figure 30. Household access to 650m<sup>2</sup> PGS within 5km in Stockholm

#### 4.2.2 Access to food retailer - Stockholm



*Figure 31. Household access to food retailer within 1km in Stockholm*

In Stockholm, 43% of households have access to a food retailer within 1km (Figure 31). When the maximum travel distance is increased to 5km, 99.99% of households have access to a food retailer. Only 6 households do not have access to a food retailer within 5km (Figure 32).



*Figure 32. Household access to food retailer within 5km in Stockholm*

### 4.2.3 Resilience category - Stockholm

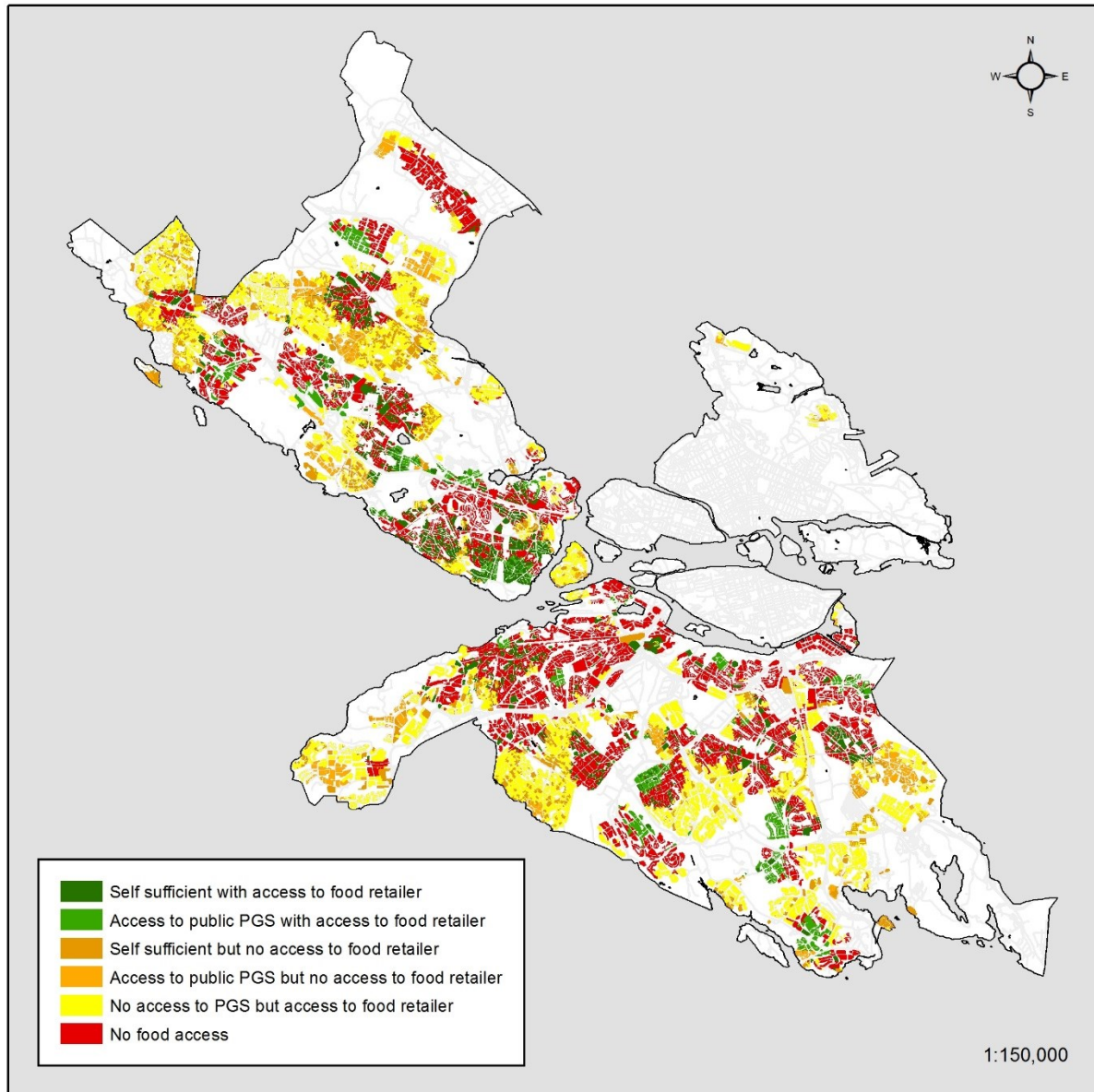


Figure 33. Household resilience category for 70m<sup>2</sup> PGS requirement within 1km scenario in Stockholm

Using the 70m<sup>2</sup> PGS requirement within 1km scenario (Figure 33), 8.5% of households fall into the *Self sufficient with access to food retailer* category. The largest proportion of this category are households categorised as *No access to PGS but access to food retailer* with 42% of the households, and 31% of households had *no food access* within the 1km cut-off.



Increasing the maximum travel distance to 5km (Figure 34) sees the percentage of *self sufficient* households rise to 16%, a further 43% of households have access to both public PGS and to a food retailer, and 41% of households have access solely to a food retailer. This leaves just five households with *no food access*.

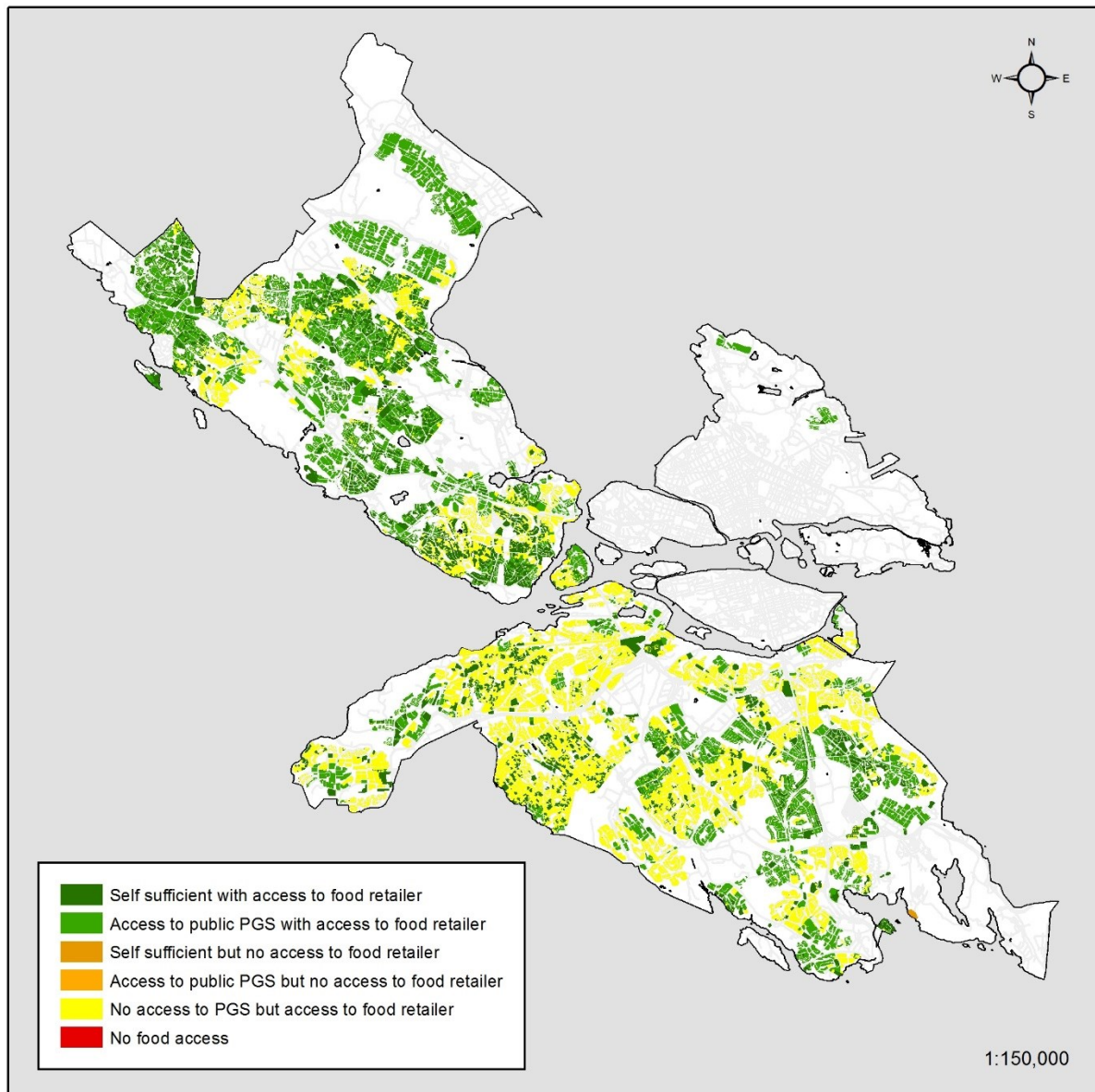


Figure 34. Household resilience category for 70m<sup>2</sup> PGS requirement within 5km scenario in Stockholm

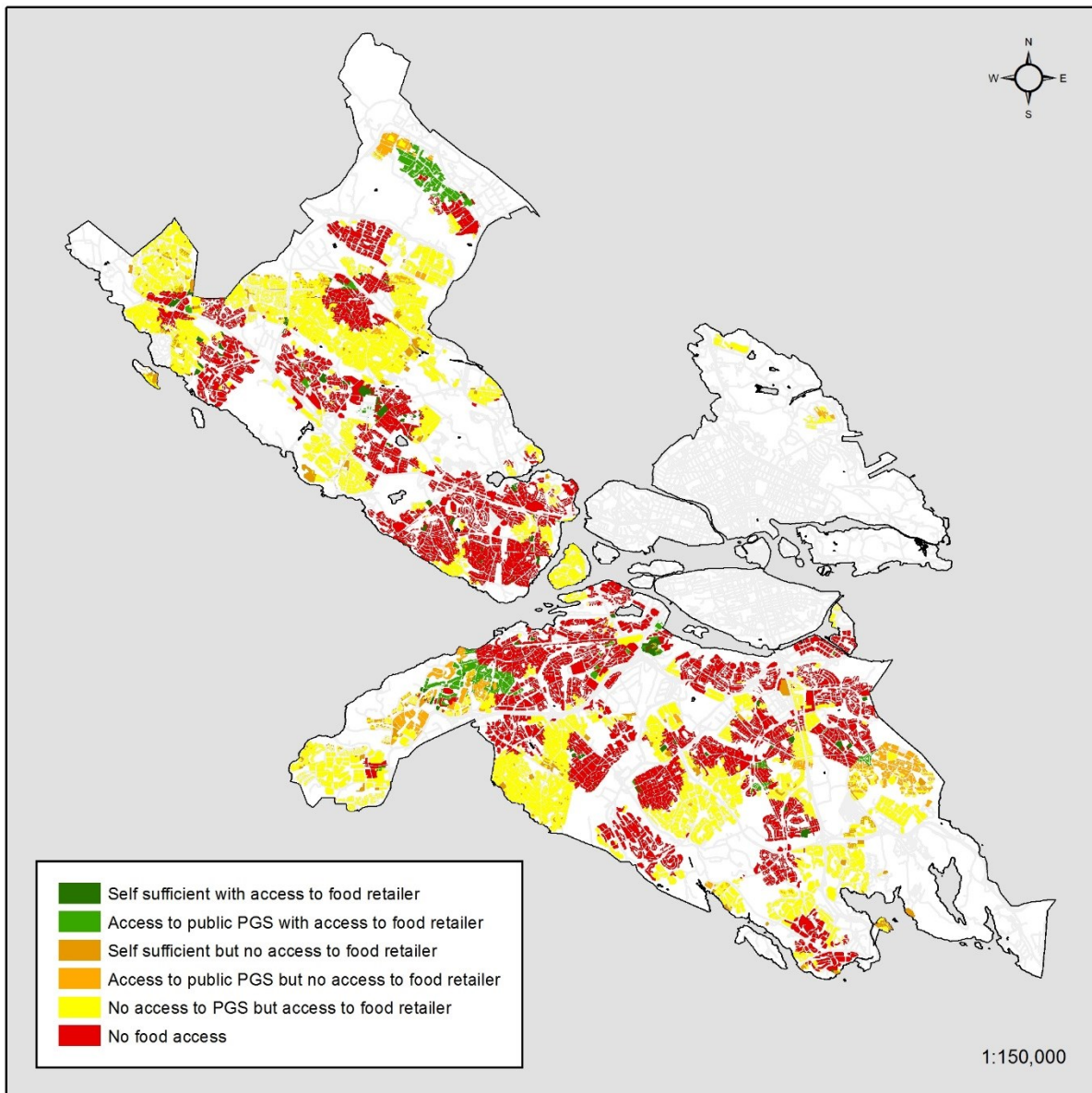


Figure 35. Household resilience category for 372m<sup>2</sup> PGS requirement within 1km scenario in Stockholm

In the 372m<sup>2</sup> PGS requirement scenario, low *self sufficient* household levels led to only 0.2% of households falling within the *Self sufficient with access to food retailer* category in the 1km maximum travel distance scenario (Figure 35), and 0.7% in the 5km scenario (Figure 36).

In the 1km maximum travel distance scenario, 51% of households had access to a food retailer but no access to the required PGS, and 41% of households were included in the *No food access* category (Figure

35). When the maximum travel distance is increased to 5km, 86% of households have access to a food retailer but no access to the required PGS, and only 5 households have no access to food (Figure 36).

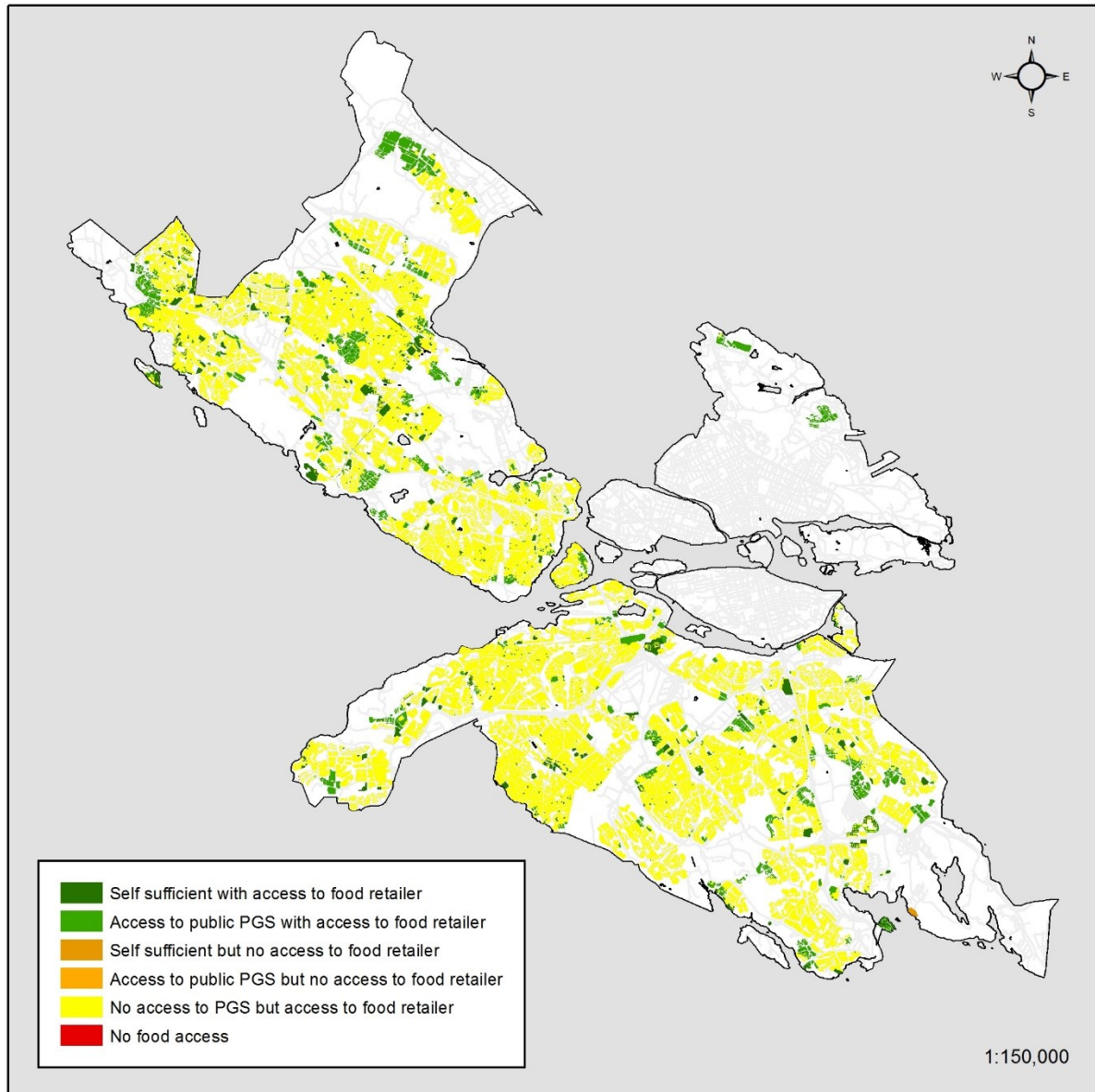


Figure 36. Household resilience category for 372m<sup>2</sup> PGS requirement within 5km scenario in Stockholm

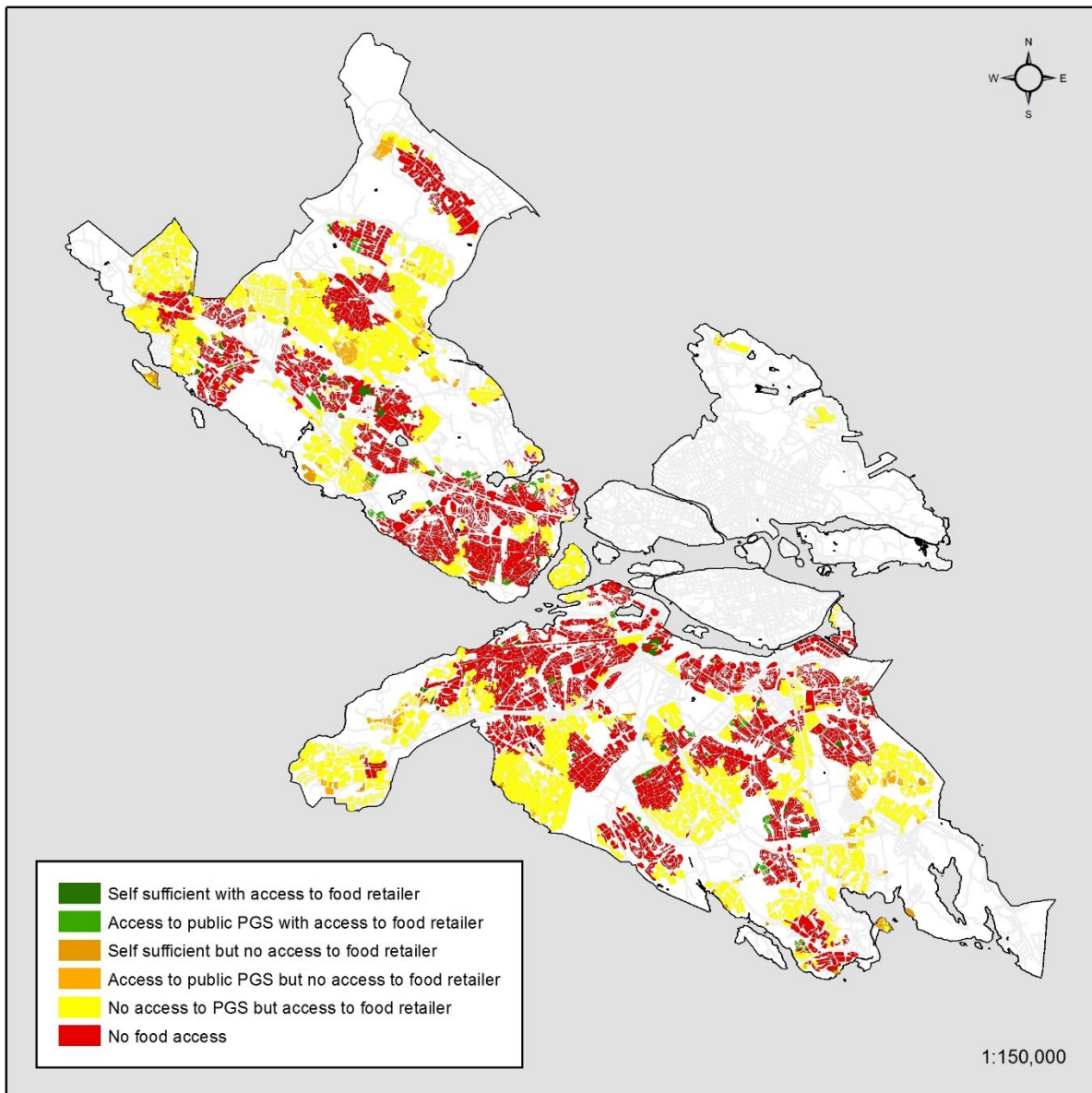


Figure 37. Household resilience category for 650m<sup>2</sup> PGS requirement within 1km scenario in Stockholm

When the 650m<sup>2</sup> PGS requirement scenario is used with the 1km maximum travel distance, 53% of households have *No access to PGS but access to food retailer*, and a further 43% fall into the *No food access* category (Figure 37). When the maximum travel distance is increased to 5km, 92% of households fall into the *No access to PGS but access to food retailer* category, and 7% have *Access to public PGS with access to food retailer* (Figure 38).



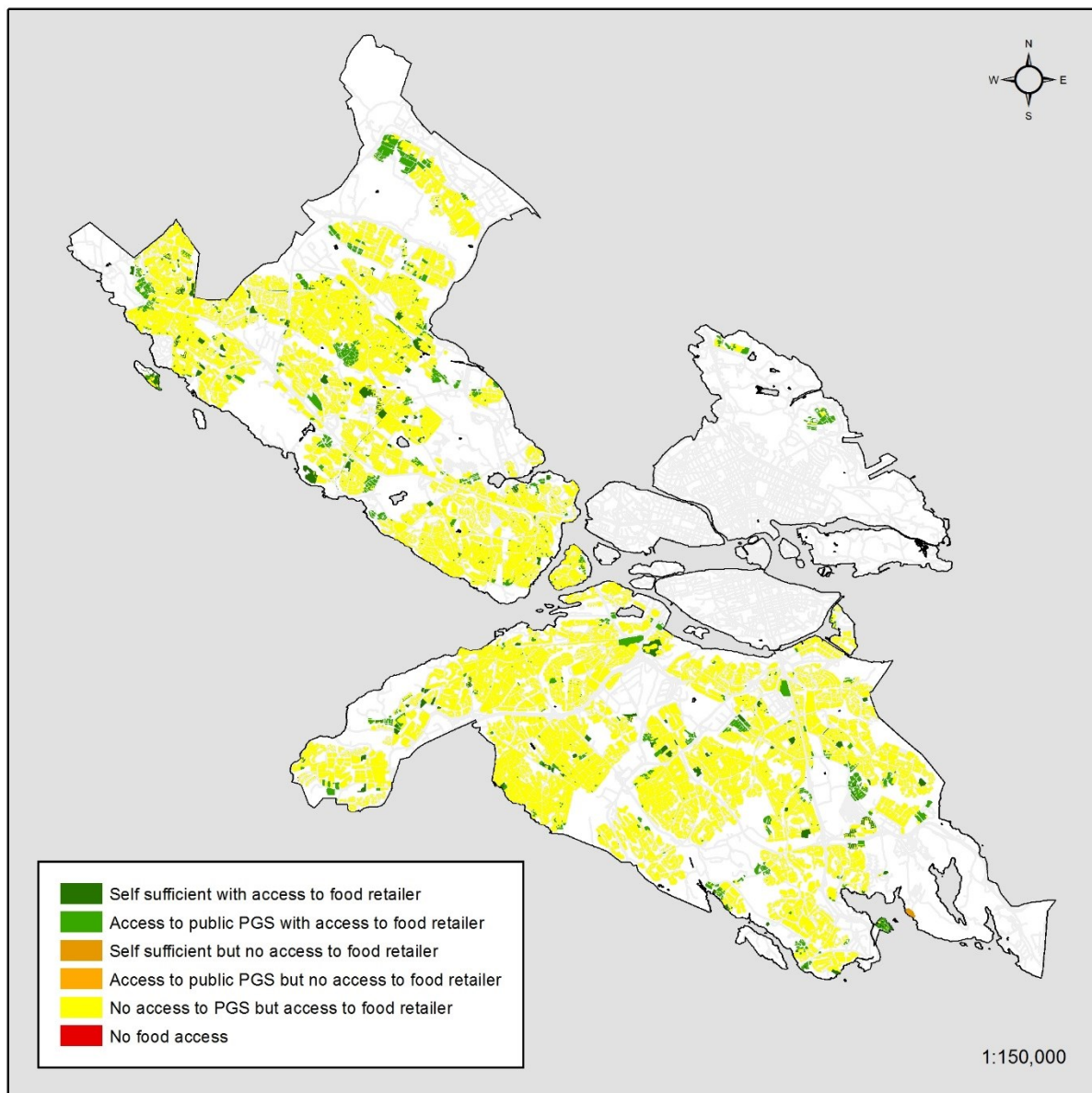


Figure 38. Household resilience category for 650m<sup>2</sup> PGS requirement within 5km scenario in Stockholm

Table 11 shows the the percentage of households that fall into each category for each scenario.

Stockholm	Households (percent of total)					
	1km			5km		
<b>Access to food retailer</b>						
Access to food retailer	43.4			99.99		
No access to food retailer	56.6			0.01		
<b>Access to PGS</b>	<b>70m<sup>2</sup></b>	<b>372m<sup>2</sup></b>	<b>650m<sup>2</sup></b>	<b>70m<sup>2</sup></b>	<b>372m<sup>2</sup></b>	<b>650m<sup>2</sup></b>
Self sufficient	15.7	0.7	0.3	15.7	0.7	0.3
Access to public PGS	10.8	5.6	3.9	42.7	10.5	6.8
No access to PGS	71.9	92.0	94.1	40.0	87.1	91.2
<b>Resilience category</b>						
Self sufficient with access to food retailer	8.3	0.2	0.1	15.7	0.7	0.3
Access to public PGS with access to food retailer	4.3	2.0	1.1	42.7	10.5	6.8
Self sufficient but no access to food retailer	7.3	0.5	0.2	0.002	0.002	0.002
Access to public PGS but no access to food retailer	6.4	3.6	2.9	0	0	0
No access to PGS but access to food retailer	41.4	51.1	52.1	40.0	87.1	91.2
No access to food	30.5	40.9	41.9	0.01	0.01	0.01

\* Total households in access to food retailer category = 50,848. total households in other categories = 50,003, the difference is due to some households not having population statistics and therefore not being included in per person calculations of PGS requirement.

Table 11. Percentage of households in each category for Stockholm<sup>2</sup>

Table 12 shows the PGS land requirements for each scenario prior to any location based analysis.

Land Required per person	70m <sup>2</sup>	372m <sup>2</sup>	650m <sup>2</sup>
<b>Total External PGS Required</b>	3,037ha	19,390ha	34,443ha
<b>Total Public Land PGS available</b>	1,965ha	1,965ha	1,965ha
<b>Difference</b>	-1,072ha	-17,425ha	-32,478ha

Table 12. PGS statistics for Stockholm

<sup>2</sup> For table of count of households see appendix 8.2.2

## 5 DISCUSSION

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This chapter will be divided into three parts: a discussion of the results of the Christchurch case study, a discussion of results of the Stockholm case study, and finally a discussion of the methodology developed in this study. As the input data from the two case studies came from different data sources and differed in structure, it is difficult to compare the results of the two cities, however some broad conclusions can be drawn from the large differences between the numbers of households in each resilience category.

### 5.1 DISCUSSION OF CHRISTCHURCH CASE STUDY RESULTS

Many Christchurch households have a garden where they could grow food, with 92% of households categorised as *self sufficient* when using the 70m<sup>2</sup> PGS requirement scenario. However, the percentage drops to 7% when using the 372m<sup>2</sup> scenario, and 2% when using the 650m<sup>2</sup> scenario. The larger PGS requirement scenarios placed a lot of pressure on public land PGS, and although there are many public land parcels in Christchurch, many of them are not big enough to cater to the greater PGS requirements. In the case of the 372m<sup>2</sup> scenario, 74% of households were unable to access the required PGS within 1km maximum travelling distance, and 87% of households using the 650m<sup>2</sup> scenario were unable to access the required PGS within 1km. These percentages dropped to 46% and 28%, respectively, when the maximum travel distance was increased to 5km, as many more of the households could be allocated space in the larger public land parcels.

Food retailers are spread across the city with a slightly higher concentration around the city centre, and lighter spread in the Eastern suburbs (Figure 6). Access to food retailers in Christchurch is good, with 99% of households located within 5km of a food retailer; however, only 37% of households were within 1km. The high accessibility of food retailers meant that few households were categorised as having *no access to food* within a 5km travel distance.

The large number of households with no access to adequate *PGS* in the larger land requirement scenarios means that food will still need to be imported to the food retailers. Further investigation into how much *PGS* or existing growing space is available in the peri-urban and close rural zones is required to determine whether the city could support itself with minimal transportation of imported food.

## 5.2 DISCUSSION OF STOCKHOLM CASE STUDY RESULTS

Many of Stockholm's households have relatively small amounts of *PGS* when compared with Christchurch; the results showing only 171 households categorised as *self sufficient* when the 650m<sup>2</sup> *PGS* requirement scenario is used. Even when using the 70m<sup>2</sup> scenario, only 7,970 households (16%) were classified as *self sufficient*. These figures put a great deal of pressure on the available *PGS* on public land. Where household populations were very high (apartment buildings or complexes), the *PGS* requirements were often too large to be assigned space in some public land parcels. If the densely-populated residential buildings within the urban centre were included, results would almost certainly show a further increase in household numbers with no access to *PGS*.

Food retailers are evenly spread across the city with a slight clustering in the city centre (Figure 10). Access to food retailers in Stockholm is very good; only six of the households in this study were not within 5km of a food retailer and 43% of households were within 1km. The high accessibility of food retailers means that few households were categorised as having *No access to food* within a 5km travel distance.

However, the large number of households with no access to adequate *PGS* throughout all scenarios means that food still needs to be imported into the food retailers. Again, as in the Christchurch case study, further investigation into how much *PGS* or existing growing space is available in the peri-urban and close rural zones is required to determine if the city could support itself with minimal transportation of imported food.

### **5.3 DISCUSSION OF METHODOLOGY**

The methodology developed in this study builds on existing research in the areas of urban agriculture and food accessibility, and their contribution to food security. The methodology is not location-specific and allows a variety of data to be input for any city. The methodology enables the incorporation of several aspects of food accessibility in the urban environment, including the identification and measurement of available potential growing space, the amount of space required to grow enough food, and measurement of the accessibility of both potential growing space and food retailers. By incorporating these concepts into a single methodology, this study offers decision-makers a more holistic approach to measuring access to food and the ability to categorise, at the household level, the resilience to food insecurity in the urban environment.

The accessibility measures are calculated using reasonable distances for walking and cycling to potential growing space, as identified in the literature. The maximum travel distance can be adjusted to suit any situation. Using distance measures for walking or cycling extends the scope of measurement of resilience by providing insight into how accessible food is when energy-dependent forms of transport are not being relied upon, due to cost, and in the case of an energy shortage due to fossil fuel decline or a catastrophic event.

The methodology makes it easy for city planners, or urban landscape decision-makers to incorporate data that may already be available into a simple model structure. Each of the datasets described in the standard data schema allows for variations in data structure, language, and quality. Due to these variations, assumptions may need to be made, and potential sources of error may need to be acknowledged.

Differences in data structure and quality can offer various sources of potential error, and have the ability to skew results. However, with careful quality assurance, it may be possible to adjust or manipulate the data to remove some of this error. Examples from Christchurch and Stockholm will be discussed here to demonstrate this.

### 5.3.1 Potential Growing Space

For the purposes of this study, only land that is assumed to be suitable for directly planting into has been included in the *PGS* datasets. Other potential sources of *PGS* that could be included in future studies are areas where structures to hold raised beds for growing food could be built such as rooftops, or unused car parking.

Had different datasets or a combination of datasets been used, the final results would have been different and this needs to be taken into account when reviewing the results. To illustrate this source of potential variation, a sample mesh block for Christchurch is used to demonstrate differences in results that may be achieved by using increasingly more accurate data.

At the most basic level, in some cases there may be no dataset for land cover, or satellite imagery to be classified available. In a case such as this, a simple dataset could be created, for example, by using the title plot area minus the area of an average house and an average sized double garage combined (150m<sup>2</sup>). This gives an approximate estimation of the remaining space on each title. Obviously, it would not be accurate across an entire city where different sized sections in different suburbs will contain houses of varying sizes. This technique also discounts areas such as driveways and patios, other utility buildings such as garden sheds, and vacant sections. However, in a situation where no data is available it may be sufficient to gain an initial understanding of *PGS* availability (Figure 39).

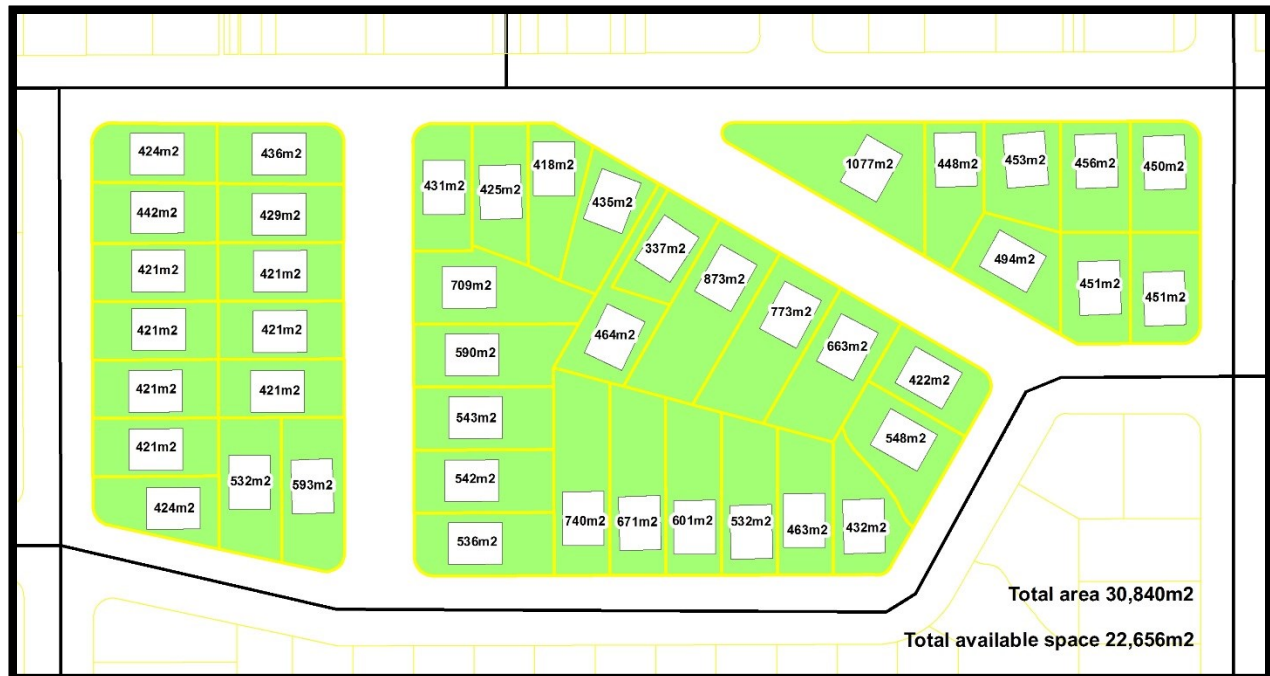


Figure 39. PGS calculated from average house and garage

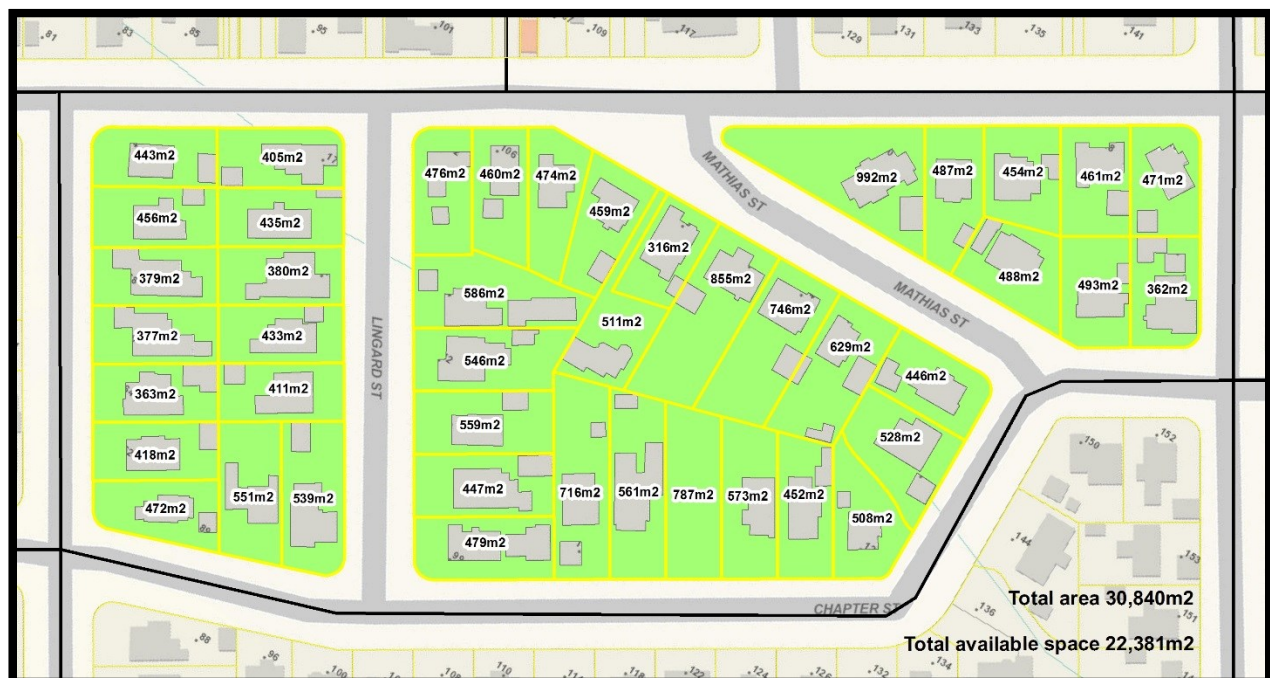


Figure 40. PGS calculated using building footprints



Figure 40 shows the same area using actual building footprints. Here it is possible to see the differences in house size and how that impacts upon the remaining uncovered area. In this case, some utility buildings are included and vacant sections are left empty. However, it is still notable that driveways and patios are not considered in the calculation.

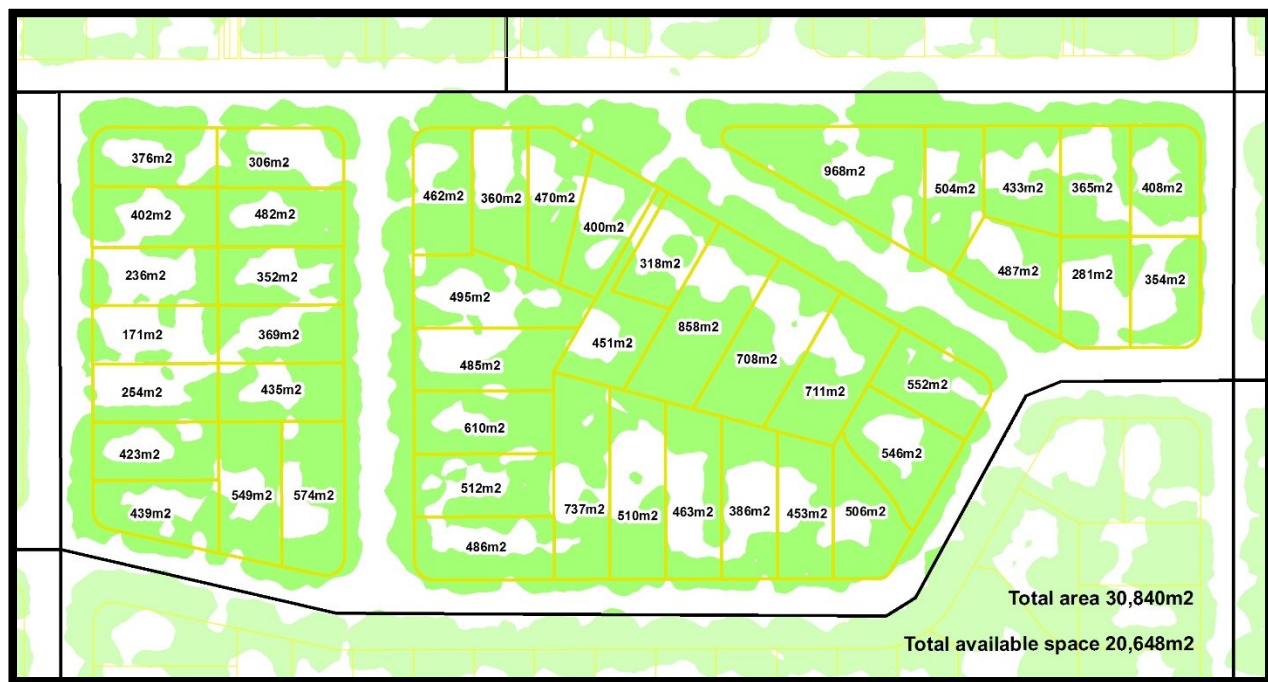


Figure 41. PGS calculated from NDVI classification

In Figure 41, the PGS dataset is derived from an NDVI classification, as used in the Christchurch case study, that shows vegetated and bare soil areas and excludes impermeable covered areas such as buildings, driveways, and patios. As can be seen in Figure 41, the differentiation between buildings and vegetation is not particularly accurate, but in a case where no building footprints are available and the image resolution is high enough, it may nevertheless be a viable option.



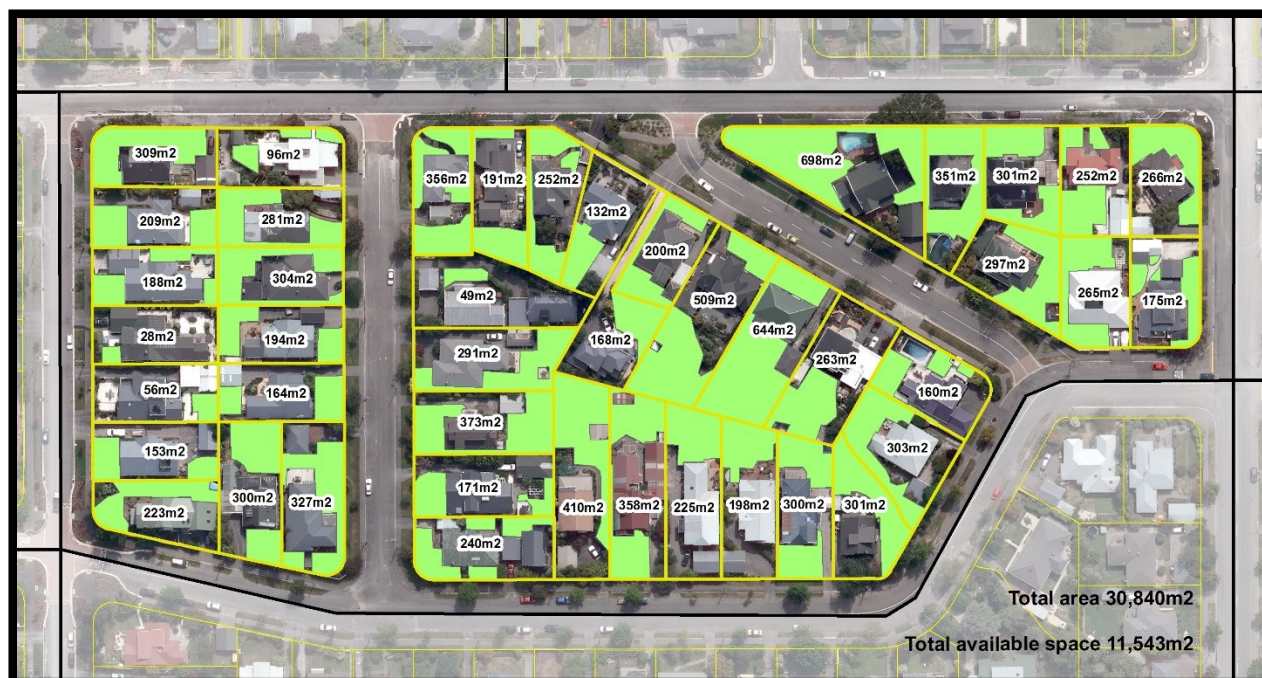


Figure 42. PGS manually digitised from high resolution aerial photography

Figure 42 shows a best-case scenario. The PGS was captured using heads up digitising from high resolution aerial photography. All buildings, driveways, patios, utility buildings and pools were excluded from the dataset. Although the process of collecting a dataset such as this may be time-consuming and laborious, the end product gives a very accurate measurement of *PGS* availability.

Table 11 shows the differences in total *PGS* from the example mesh block. Although the first three scenarios are relatively similar, the high-quality, manually digitised data gives a total that is almost half of the others. Had a data set of this quality been available for the Christchurch case study, the final results for household accessibility to *PGS* would have been significantly different.

Method	PGS Available
Average house and garage	22,656m <sup>2</sup>
Building footprints	22,381m <sup>2</sup>
NDVI	20,648m <sup>2</sup>
Manually digitised	11,543m <sup>2</sup>

*Table 13. Differences in total PGS from various capture techniques*

### 5.3.2 PGS requirement

The amount of *PGS* required per person will depend on many factors and variables: the style of gardening to be used; the percentage of food required to be grown; the climate; the gardening skills and knowledge required; the types of crops to be grown; whether or not animals will be raised on the land; the soil quality; whether greenhouses will be used; the individual's physical ability; etc. Because of these and many more variables, and as demonstrated by the background literature, there is no hard and fast rule on how much land is required for growing one's own produce.

Both case studies used in this research used three area values per person: 70m<sup>2</sup>, 372m<sup>2</sup>, and 650m<sup>2</sup>. These area values were included to demonstrate how changing the input variables can affect the final results. If more accurate estimations of land requirements were available for any given city, these could be included and would increase the accuracy of the results. The ability to change the land requirement value offers the additional benefit of enabling several scenarios to be investigated, as has been done in this study, and comparisons can be drawn to gain further insight into the effects of differing land availability.

The results from the case studies using the larger *PGS* requirement values highlight particularly well the importance of agricultural land in the peri-urban area. In the case of energy shortages that mean long distance transportation may not be possible, having enough space near to the city to provide food to retailers is of great importance.

### 5.3.3 Capacitated location-allocation

The capacitated location-allocation method employed in the methodology allows capacity thresholds to be included when allocating *PGS*. For example, a parcel of *Public Land* may have 100m<sup>2</sup> of *Available PGS*. All households within the maximum travel distance, that require *External PGS* can be allocated space in the *Public Land* parcel until it reaches capacity of 100m<sup>2</sup>. If a household *PGS requirement* exceeds the total available it will not be given any allocation. Therefore space in the nearest *Public land* parcel may not always be allocated. If there is not enough *Available PGS* in a *Public Land* parcel within the *maximum travel distance*, no allocation of *PGS* is given to the household.

There are two sources of potential error that should be considered when using this method. The first is that partial allocation is not an option, i.e. if the *External PGS requirement* in the *Household* data set is larger than the *Available PGS* capacity in the *Public Land data set*, partial allocation will not be offered. When *Households* with very large populations, such as apartment blocks, have large *External PGS Required* values, the requirement may outweigh that of the capacity. For example, one *Household* (potentially an apartment complex) in Stockholm has a calculated population of 800; even with the lowest land requirement per person of 70m<sup>2</sup>, the *External PGS Requirement* was 56,000m<sup>2</sup>.

The second source of error when using the capacitated location-allocation method can be seen when *Public Land* parcels are very large. When *facilities* (in this case *Public land* parcels) are used in network analysis, the central point of the parcel (the centroid) is used as the network location. If parcels are very large, the centroid can lie outside of the *maximum travel distance* from the demand point (in this case the *Household*). Any *Households* that are outside of the *maximum travel distance* to the *Public Land* will not be allocated space, even when the *Household* parcel is physically located very near to the *Public Land* parcel.

An example of this error can be seen in the Stockholm case study. Figure 43 shows a large parcel of *Public Land* with over 424ha of *Available PGS*, however, when the network analysis was executed, only

*Households* within 1km of the parcel centroid were allocated space, even though many more *Households* were within the 1km of the actual *Public Land* parcel.

A potential workaround for this would be to divide the large areas into smaller parcels. However, if doing this, the first potential error of areas being too small needs to be considered. The process of parcel division needs to be reviewed on a case-by-case basis, but with careful manipulation, it could offer higher quality results.

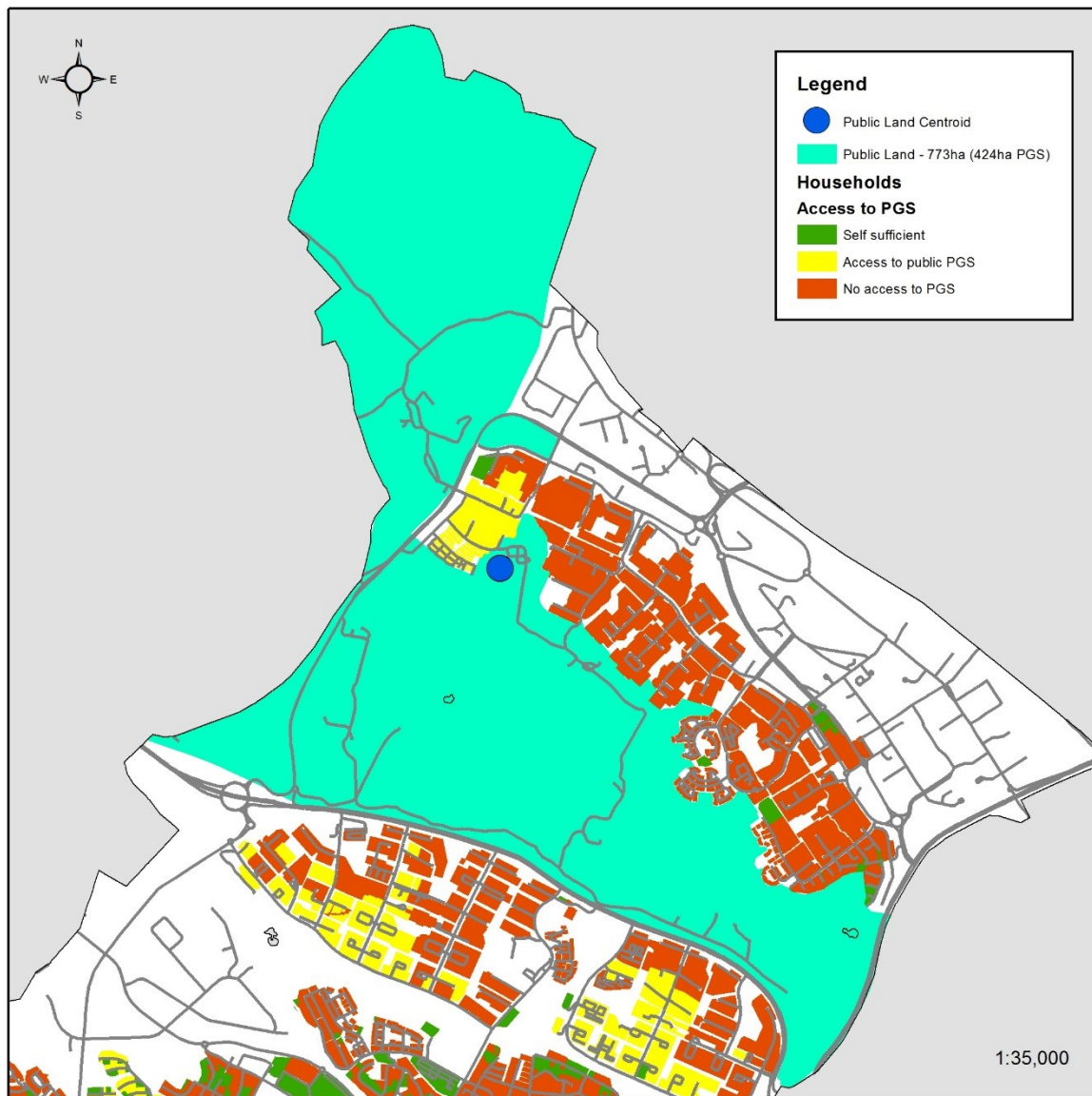
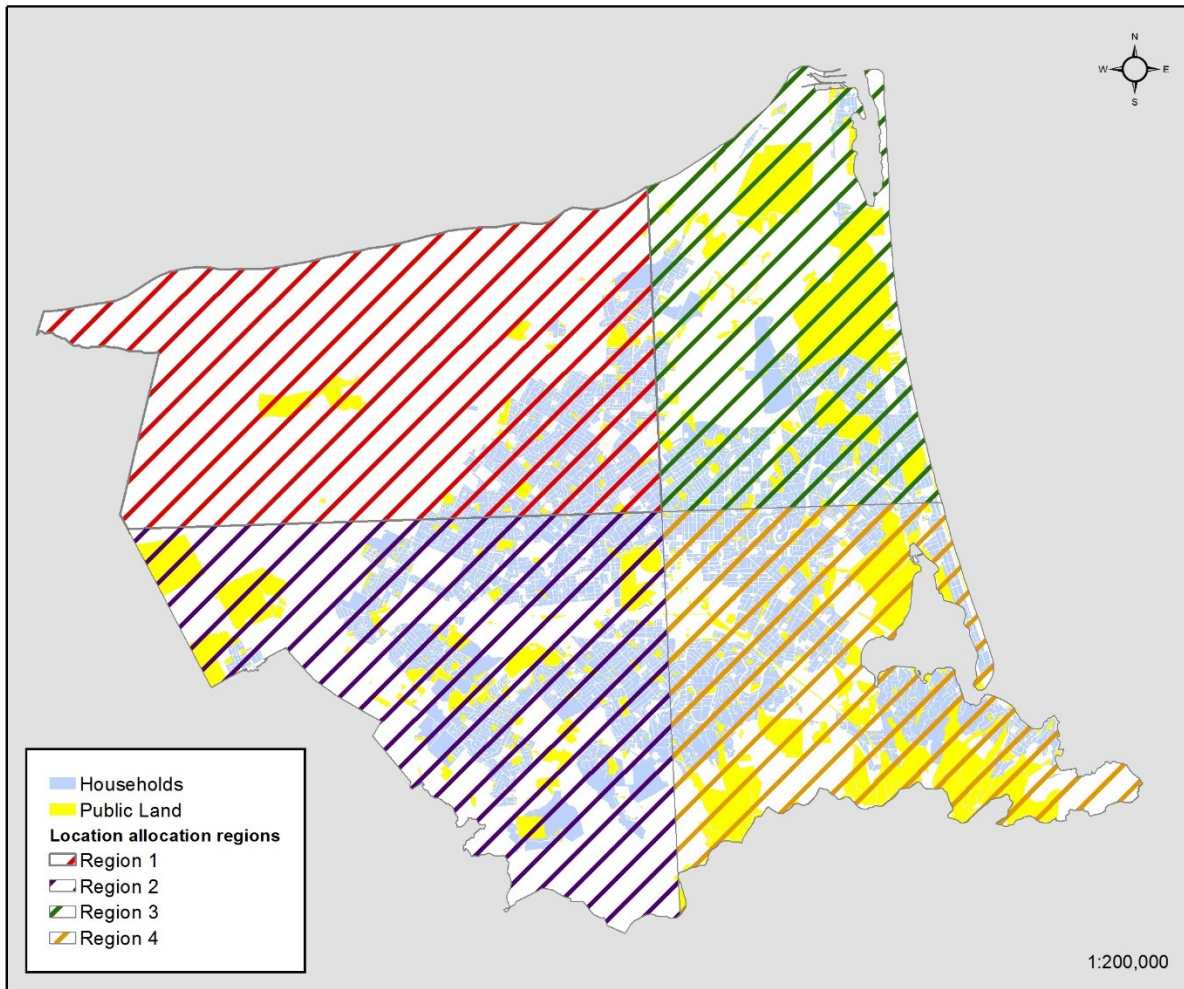


Figure 43. Stockholm Household Accessibility to PGS within 1km – Network Analysis Error

Some very large datasets need to be divided into smaller data sets to be processed. This was the case during the processing of the Christchurch data for the 372m<sup>2</sup> and 650m<sup>2</sup> *PGS* requirement scenarios using the 5km maximum travel distance. The complete datasets were too large to be processed, so to overcome the problem, the *Household* and *Public Land PGS* datasets were divided into four sector areas (Figure 44). These sectors divided the Christchurch data into four smaller sets of data which could be processed with the location-allocation tools. The division of the data in this fashion can cause variance in the results due to the *Modifiable Area Unit Problem* (MAUP) as described by Openshaw (n.d.), where different aggregations of data result in different outputs. Households that may have been allocated PGS in a certain parcel of public land in the original, undivided dataset, may not have received the same allocation when the dataset was divided into four, because the originally allocated land was now in another sector. In the Christchurch case study, the sectors divided the city into four similar-shaped areas, but boundaries for suburbs or boroughs could just as easily have been used. Using political or regional boundaries to split the data may offer similar problems to that of using the city boundary in the first instance, as this in itself is a potential cause of the error for households that are not able to be allocated land from public land parcels across the boundary.





*Figure 44. Division of Christchurch for location allocation method data processing*

Accessibility measurement is an important component of the methodology described in this research, therefore the underlying travel network data used in the analysis should be of the highest quality available. In both case studies presented here, the only data available was a simple road network. The network is used for measuring distance, and although more complex input information such as traffic light stop times and traffic flow are not required, the addition of walking or cycling routes would improve the quality of the accessibility results. By including walking or cycling only routes or paths, distances to both *PGS* and

*Food retailers* could be reduced by allowing ‘shortcuts’ (Rendall, Page, Reitsma, Van Houten, & Krumdieck, 2011).

### **5.3.4 Population**

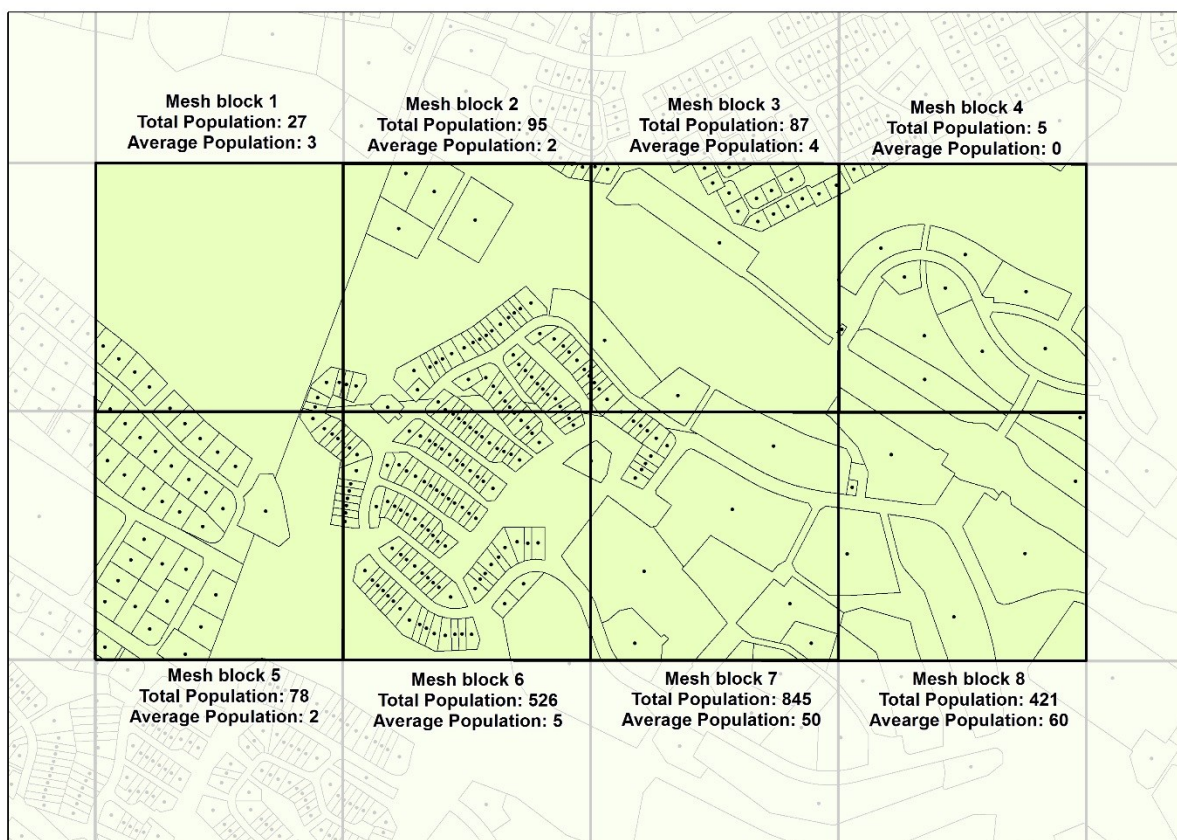
When considering how much food is required to meet the needs of an urban population, it is important to know where households are located in relation to where food can be grown or purchased, particularly when maximum travel distances are being used. Areas of high population density are likely to have less available *PGS* than areas with low population density. Apartment buildings, particularly those in central locations, may have little or no *PGS* available on the land parcel, but may house a relatively high proportion of the population when compared to residential houses on the fringe of the city with large gardens. To cater for the food requirements of large populations in high density housing, a large area of *PGS* is required. This amount of land may simply not be available within a practical distance of the home. Thus, by including location in the equation, it is possible to identify the areas of the urban environment that are most at risk of not having access to food.

In both case studies undertaken in this research, an average mesh block or census area unit population was used. It was not possible to gain access to actual household level population data, therefore mean population figures were used. Using mean population figures can cause inaccuracies by skewing results; for example, in Christchurch, most mesh blocks have an average population of two or three, so properties that house large or small populations are lost.

Accurate household population figures are of great importance when calculating *PGS* requirements and *PGS* availability at the household level. Small properties with a single occupant may have enough space to grow all of their food in reality, but when the space calculation uses a population value of three, it can cause the *PGS* availability to fall short. Similarly, a large property with a high *actual* population, potentially an apartment building, which has a relatively small amount of space, may be considered to be self sufficient when a population value of three is used.

For the purposes of this study it was assumed that all properties included were private households, and therefore they were given a population value. It is likely however that some of the properties will be vacant or will be used for other purposes such as small-scale retail services, the assumption has been made, however, that these will be in the minority.

The Stockholm case study, as well as sharing the same issues described above with reference to mean population, offered a further complication related to the Stockholm census data. The Stockholm Census area units are made up from a 250m x 250m grid covering the city, and population is included as a total population for each grid. Therefore, average household population was calculated by creating centroids for each household, which were then counted and the total population was divided by this count figure (see Figure 45).



*Figure 45. Showing property centroids used for calculating average population*



A notable error is created when this average population calculation technique is used. By looking at the housing estate in *Mesh Block 6* in Figure 45, it is possible to see that the housing estate is made up of mostly similarly sized parcels. It could be assumed that these households contain similar populations (five persons). However, when the parcels spill over into *Mesh Block 7*, the average population leaps to 50 people. The reason for this becomes more apparent when building footprints are added to the map (see Figure 46).

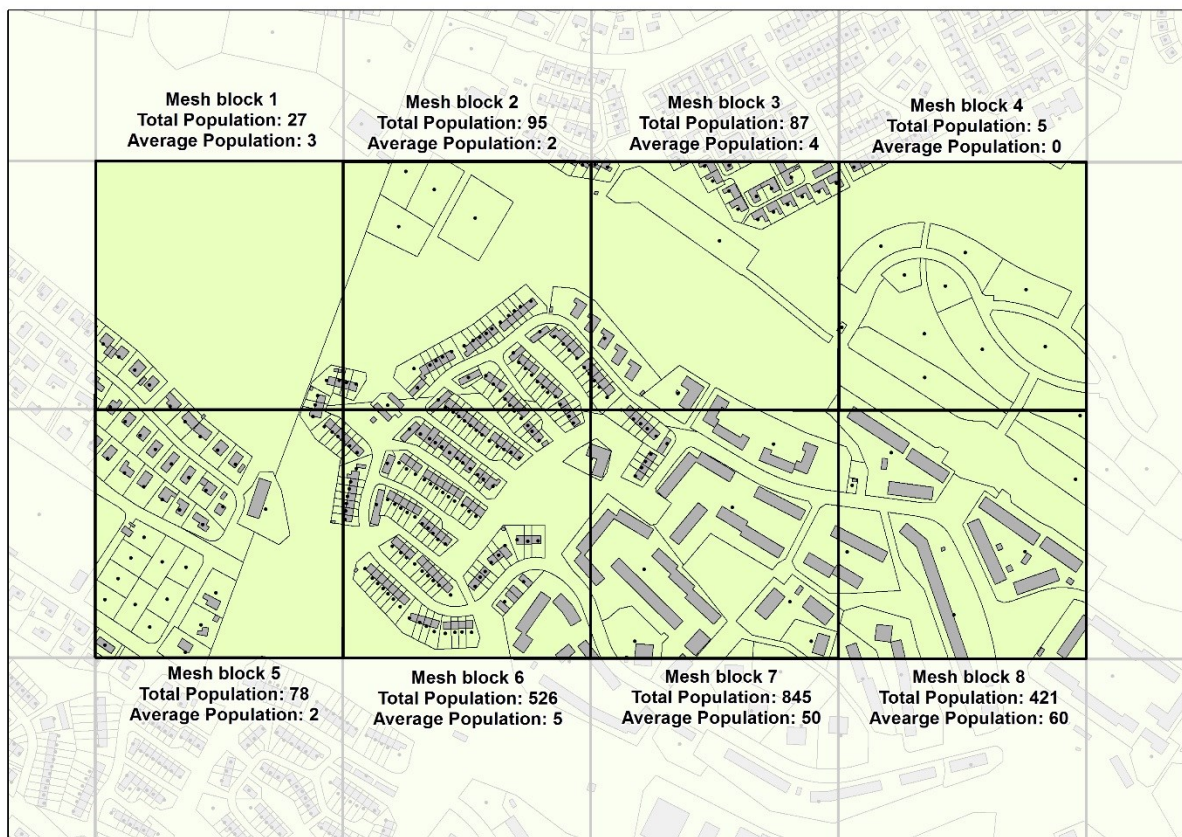


Figure 46. Showing property centroids used for calculating average population along with building footprints

When building footprints are added, it is possible to infer that the larger properties in *Mesh Block 7* are apartment buildings; this gives an entirely plausible explanation for such large average populations.

However, a source of error for the smaller properties is introduced. This population error will heavily impact on the *PGS* requirement calculation for these smaller household parcels.

All of the sources of error relating to population that are described above, both for Christchurch and for Stockholm, could be removed by using household level population data. Gaining access to this information would not only allow higher quality results to be made available, but would also allow the inclusion of residential properties in other non-residential planning zones.

## **5.4 FUTURE DIRECTIONS**

The addition of extra variables to the methodology would offer further insight into how urban agriculture may be able to assist cities to become more resilient to food insecurity. These extra variables may include the area of rooftops that could be used for rooftop gardening, or the amount of unused impermeable land that could be used for raised bed gardening. A water availability variable would be useful and this could also be used to investigate the use and viability of hydroponics and aquaculture in the city.

The integration of peri-urban space into the methodology could be used to increase the accuracy of results and, along with the inclusion of local commercial agriculture or private agriculture on public land, may offer a more insightful measure of how resilient a city is, particularly if the food retailers in the city are to be stocked from these sources.

## 6 CONCLUSIONS

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Food security in urban environments is becoming an increasingly important issue worldwide; urban expansion and urban infilling means that city populations are rising while the amount of available land for growing food is reducing. Many cities have developed, or are in the process of developing, food security strategies in order to deal with potential future food shortages. Urban agricultural activity is included in many of these strategies as a means of decreasing the amount of food that needs to be imported, which is particularly important when the inevitable decline of fossil fuels is taken into account.

Recent research has focused on the availability of land for urban agricultural activity, how much land is being used, and how much land is required to feed city populations. Other studies have looked into the accessibility of commonly-used services such as schools, hospitals and shops to urban populations. The present study brings together research in these two areas in order to develop a methodology that can be used to investigate food accessibility at the level of the urban household, as determined by access to growing space and food retailers. Accessibility of food at the household level is a key indicator for determining how resilient households are to food insecurity.

The methodology developed in this thesis allows households to be placed into resilience categories by combining data on the accessibility of potential growing space and food retailer locations. A non location-specific data structure is employed, which means data from any city can be used. Additionally, input variables can be changed, for example, different *PGS* requirements (i.e. the 70m<sup>2</sup>, 372m<sup>2</sup>, and 650m<sup>2</sup> scenarios), or different maximum travel distance scenarios (i.e. 1km or 5km) can be used.

The results of this study show that using [non] standard input datasets has the potential to create sources of error; however, with careful quality assurance and data manipulation, many of these potential sources of error can be avoided.

The case studies of Christchurch and Stockholm demonstrate how potential growing space availability and food retailer locations impact upon the number of households in the different resilience categories used in the methodology. In both studies, increasing the maximum travel distance to 5km from 1km made a significant difference to the number of households that were able to access PGS, and also resulted in large percentages of households having access to food retail stores.

This study has shown that food retailer locations relative to household locations play a key role in the supply of food to the urban populations of Christchurch and Stockholm. It is clear that extending the scope of this methodology to the peri-urban area in future research would provide a better understanding of the overall resilience to food insecurity of any given city, by giving more accurate estimates of the amount of food that could be produced locally.

The methodology developed in this thesis is adaptable, and can be used to model the potential effects of different scenarios, such as the addition of new subdivisions or changes in public land use. It can be used by city planners and decision-makers to make decisions about where potential growing space needs to be protected or allocated, and where food retailers are needed, and thus contributes to increasing the resilience of cities to food insecurity.

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## 8 APPENDICES

### 8.1 DATA SCHEMA

#### 8.1.1 Households

Simple feature class				Geometry	Polygon		
<b>Households</b>				Contains M Values	No		
				Contains Z Values	No		
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
PAR_ID	Long Integer	No			0		
TOTAL_AREA	Double	No			0	0	
POPULATION	Long Integer	No			0	0	
PGS_REQ	Double	No			0	0	
PGS_AVAILABLE	Double	No			0	0	
EXT_PGS_REQ	Double	No			0	0	
ACCESS_PGS	Text	No					50
ACCESS_FR	Text	No					50
RES_CAT	Text	No					75
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

### 8.1.2 Public land

Simple feature class					Geometry	Polygon	
<b>PublicLand</b>					Contains M Values	No	
					Contains Z Values	No	
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
PAR_ID	Long Integer	No			0		
TOTAL_AREA	Double	No			0	0	
AVAILABLE_PGS							
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

### 8.1.3 Population

Simple feature class					Geometry	Polygon	
<b>Population</b>					Contains M Values	No	
					Contains Z Values	No	
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
CB_ID	Long Integer	No			0		
TOTAL_POP	Long Integer	No			0		
AVERAGE_POP	Long Integer	No			0		
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

### 8.1.4 Planning zones

Simple feature class					Geometry	Polygon	
<b>PlanningZones</b>					Contains M Values	No	
					Contains Z Values	No	
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
Zone	String	No					50
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	

### 8.1.5 Road network

Simple feature class					Geometry	Polyline	
<b>Roads</b>					Contains M Values	No	
					Contains Z Values	No	
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
Shape_Length	Double	Yes			0	0	

### 8.1.6 Potential growing space

Simple feature class					Geometry	Polygon	
<b>PGS</b>					Contains M Values	No	
					Contains Z Values	No	
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
Shape_Length	Double	Yes			0	0	
Shape_Area	Double	Yes			0	0	



### 8.1.7 Food retailers

Simple feature class				Geometry	<i>Point</i>		
<b>FoodRetailers</b>				Contains M Values	<i>No</i>		
				Contains Z Values	<i>No</i>		
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale	Length
OBJECTID	Object ID						
Shape	Geometry	Yes					
Store_ID	Long Integer	No			0		

## 8.2 TABLES OF COUNTS OF HOUSEHOLDS IN EACH CATEGORY

### 8.2.1 Christchurch

Christchurch	Households (count)					
	1km			5km		
Access to food retailer						
Access to food retailer	51,805			138,405		
No access to food retailer	88,412			1,812		
Access to PGS	70m²	372m²	650m²	70m²	372m²	650m²
Self sufficient	125,466	8,952	2,932	125,466	8,952	2,932
Access to public PGS	10,605	26,409	14,916	11,570	62,830	38,914
No access to PGS	973	101,683	119,196	8	65,262	95,198
Resilience category						
Self sufficient with access to food retailer	45,195	3,468	1,144	123,775	8,762	2,875
Access to public PGS with access to food retailer	5,251	7,438	5,206	11,518	61,496	37,612
Self sufficient but no access to food retailer	80,271	5,484	1,788	1,691	190	57
Access to public PGS but no access to food retailer	5,354	18,971	9,710	52	1,334	1,302
No access to PGS but access to food retailer	744	40,284	44,840	0	65,035	94,806
No access to food	229	61,399	74,356	8	227	392

\* Total households in access to food retailer category =140,217, total households in other categories = 137,044 due to not all households having population statistics.

Table 14. Count of Christchurch households in each category

## 8.2.2 Stockholm

Stockholm	Households (count)					
	1km			5km		
<b>Access to food retailer</b>						
Access to food retailer	22,047			50,842		
No access to food retailer	28,801			6		
<b>Access to PGS</b>	<b>70m<sup>2</sup></b>	<b>372m<sup>2</sup></b>	<b>650m<sup>2</sup></b>	<b>70m<sup>2</sup></b>	<b>372m<sup>2</sup></b>	<b>650m<sup>2</sup></b>
Self sufficient	7,970	372	171	7,970	372	171
Access to public PGS	5,471	2,866	2,008	21,691	5,354	3,466
No access to PGS	36,562	46,765	47,824	20,342	44,277	46,366
<b>Resilience category</b>						
Self sufficient with access to food retailer	4,237	121	62	7,969	371	170
Access to public PGS with access to food retailer	2,206	1,028	557	21,691	5,354	3,466
Self sufficient but no access to food retailer	3,733	251	109	1	1	1
Access to public PGS but no access to food retailer	3,265	1,838	1,451	0	0	0
No access to PGS but access to food retailer	21,063	25,972	26,501	20,337	44,272	46,361
No access to food	15,499	20,793	21,323	5	5	<b>5</b>

\* Total households in access to food retailer category = 50,848, total households in other categories = 50,003 due to not all households having population statistics.

Table 15. Count of Stockholm households in each category